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PREFACE.

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Hampstead, Jan. 1833.

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MR. POWELL. — CAN any of you, my children, tell me why the handle of the tea-pot your mamma is using is made of wood?

HARRIET. — I suppose, papa, it is to prevent the hand from slipping, as it would do on a polished silver handle.

MR. P. — No, that is not the principal reason, my dear. The handle is made of wood to prevent it from becoming too hot to hold, as it would do if made of metal.

HARRIET. — Why should a metal handle become hotter than a wooden one?

Mr. P. — Because metal is a better conductor of heat than wood, and the heat from the boiling water in the tea-pot would therefore be sooner conveyed to it.

Mrs. P. — You may quickly convince yourself of that, Harriet, by touching the silver at the point where it and the wood join. If, in making tea, you allow your finger to slip off the wooden handle, you will soon feel the metal burn you.

Frederick. — Is it for the same reason that people use paper and woollens to take hold of the kettle, or hot irons?

Mr. P. — Yes. Paper and woollens are, comparatively, bad conductors of heat; therefore it is longer in penetrating them.

Robert. — But, I suppose, when the heat has once got through them, they would be as hot as metals.

Mr. P. — They would *be* as hot, but they would not *feel* nearly so hot as metals of the same temperature. The property metals possess of becoming quickly heated, when brought near to a heated body, also disposes them to part with their heat quickly, when touching a colder substance. Both effects are produced by the facility with which metals conduct heat.

Robert. — But I cannot understand how the same cause that makes metals sooner hot than other things, should make them cool sooner also.

Mr. P. — I will endeavour to explain the difficulty. When any cold substance touches a heated

body, it takes away a portion of the heat from the part it touches; and, if the heated body be a bad conductor, it will require more time before that part which is deprived of heat can be again supplied with it from the other parts of the heated body. In this manner the heat will be retained longer in the bad conductor. In metals, on the contrary, the heat is quickly conveyed from *every part* of the metal to any substance touching them, consequently they become sooner cold. Thus, you perceive, a heated piece of metal must feel hotter than a heated bad conductor, because, though both may be really equally hot, the metal gives out its heat more rapidly.

Frederick. — Yes; I see now what you mean, father; heated metals feel hotter than woollens, because they give out a greater quantity of heat in the same time.

Mrs. P. — This will also explain to you, I think, the cause of the money in your pockets feeling so hot, at which you were puzzled so much the other day when standing by the fire.

Mr. P. — Exactly so.

Robert. — But how can we tell that the metal is not the hottest after all?

Mr. P. — By means of the thermometer we may ascertain their degrees of heat to be the same. It is true, if you were to surround the bulb of the thermometer with heated metal, the mercury in the tube would rise more rapidly than when covered with heated woollen; but in a short time

the woollen would raise the mercury as high as the heated metal. I can convince you that metals conduct heat more quickly than wood, by a very simple experiment.

Robert. — I should like to see it, father.

Mr. P. — This silver spoon and this wooden one are of the same length, you perceive: hold one in each hand at the farthest end, and dip them both into this bason of boiling water. (*Robert does as his father desires; but, after holding the spoons about a minute, he lets the silver one fall into the bason, and draws his hand quickly away.*) What is the matter, Robert? — you shake your hand as if the silver spoon burnt you.

Robert. — And so it did. It is so hot I could not hold it any longer.

Mr. P. — How does the wooden spoon feel?

Robert. — Scarcely warm where I have hold of it; though, lower down, it is quite hot.

Mrs. P. — I think you must be satisfied now, Robert, that silver conducts heat more quickly than wood, as you have burnt your fingers in the trial.

Robert. — Yes, it must be so: but do all metals, father, conduct heat as quickly as silver?

Mr. P. — No, my dear, they vary very considerably. It has been found, by recent experiments, that gold is the best conductor; next to gold is silver; then copper, iron, and tin. Lead possesses this property in a much lower degree.

Harriet. — If the heat of the water made the

silver spoon so soon hot, I suppose water is a good conductor of heat also?

Mr. P. — You are mistaken there, Harriet; for water is not only a very bad conductor of heat, but it has been supposed to be not capable of conducting heat at all.

Harriet. — Then how could it part with its heat so rapidly to the spoon?

Mr. P. — The particles of the water were put in motion by Robert when he plunged the spoons into the bason; therefore a fresh portion of the heated water was every instant made to touch the spoons, and the silver one quickly took the heat from the different particles as they touched it. Had the water been in a state of perfect rest, the spoon would not have been heated nearly so soon, because the heat taken away from those particles immediately surrounding the spoon could not have been renewed by the heat in the other part of the water, owing to its non-conducting property.

Frederick. — Is the heat in liquids communicated, then, by their motion, rather than by their power of conducting heat?

Mr. P. — That is generally the case, Frederick, and whilst their particles keep in motion, and are thereby presenting a constantly changing surface to the body touching them, the heat will be supplied as fast as it can be conducted away.

Robert. — Can you show us that this is the case by any experiment?

Mr. P. — There are several experiments by which I could convince you that water, when not in motion, is a very bad conductor. I will show you one now.

Harriet. — Do, dear papa, for I delight in experiments, they seem to make things so clear.

Mr. P. — I will half fill this ale-glass with cold water, and put the bulb of the thermometer into it, that we may see if any change take place when I pour hot water upon the cold. You observe, the thermometer in the glass is now at 50°. I place this piece of paper on the top of the cold water, whilst I pour the hot water gently upon it, to prevent their mixing.

Harriet. — The hot water you are pouring in is of a different colour from the cold.

Mr. P. — I have put a little ink into it, to enable us to distinguish the two waters.—You see I have poured the water so gently that they have not mixed. I will now remove the small piece of paper that divides the hot from the cold water, and if I do so carefully, they will remain nearly as distinct as they are now. (*Mr. Powell removes the paper.*) You see the hot water remains in a separate layer at the top.

Harriet. — How very curious it is that they do not mix!

Frederick. — The thermometer has risen only three degrees, though the coloured water must be nearly boiling hot, and is within two inches of the bulb.

Mr. P. — Nor will it rise much higher if it remain in the water half an hour. I hope this experiment convinces you, Robert, that water, when at rest, is a very bad conductor of heat. Indeed, most fluids, with the exception of quicksilver, are very imperfect conductors, and impart heat to, and abstract it from, surrounding bodies, principally by the agitation of their particles, in consequence of which a fresh surface is constantly brought into contact with the body they surround. It is in this manner that air, which is a bad conductor, becomes capable of communicating and taking away heat very rapidly.

Harriet. — But, papa, I have noticed that as soon as I come in sight of a large fire, I feel a glow upon my face; is it owing to the heat being conducted by the air in that way?

Mr. P. — The effect you have observed is produced by another most interesting property of heat, called *radiation.*

Frederick. — What do you mean, father, by the radiation of heat?

Mr. P. — It has been discovered that all bodies, besides communicating heat to substances touching them, have the power of emitting heat from their surfaces, as rapidly as light. As the heat thus emitted proceeds from bodies in straight lines, in all directions round them, like the radii from the centre of a circle, it is hence called radiant, or radiated, heat, to distinguish it from conducted heat. The quantity of heat radiated from different bodies

depends more upon their surfaces than upon their internal qualities. Highly polished metals radiate the least heat, and dark substances the most.

Mrs. P. — Is not that the reason why metal tea-pots make tea so much better than dark earthen-ware ones?

Mr. P. — It is supposed to be the cause.

Frederick. — Do hot things, in cooling, part with much of their heat in this way?

Mr. P. — It depends greatly upon the nature of the body cooled, but, generally, about as much heat is lost by radiation as by communication. The intensity of radiated heat diminishes as the squares of the distance increase; that is, at twice the distance from the radiating body, there is only one quarter of the heat. Therefore a person sitting at a distance of two yards from the fire receives only one fourth part as much heat from it as another person sitting at a distance of but one yard. In this respect, and indeed in most others, radiant heat is subject to the same laws as light, with which it is closely connected.

Frederick. — Thank you, father, for telling us so much. There is scarcely a day passes that I do not see something I cannot understand; but I think if I could learn as much every day as I have learnt this evening about heat, I should soon be able to find out many of the things that now puzzle me.

Mr. P. — I am glad you have such a thirst for knowledge, Frederick; and during these Christ-

mas holidays I will find time to explain to you the principles upon which many of the common occurrences of life depend.

Robert. — Let me be present, too, father.

Harriet. — And me, papa.

Mr. P. — Most willingly.

Harriet. — Dear papa, when will you begin?

Mr. P. — To-morrow morning, in my study, immediately after breakfast.

CONVERSATION II.

WARMTH OF CLOTHING.

Mr. POWELL'S *Study*.—*Mr.* POWELL, FREDERICK, ROBERT, *and* HARRIET.

MR. P. — AFTER our conversation of yesterday, I dare say none of you will have any difficulty in answering why woollens and furs are chosen for clothing in cold weather, and why metals usually feel so cold.

ROBERT. — Oh no! Woollen cloth is so much warmer than metals, that I am sure no one in his senses would think of wearing metal near his skin in such weather as this.

MR. P. — Well, since you are so certain about woollens being warmer than metals, take the thermometer, wrap the bulb round with wool, and tell me how high it rises.

ROBERT. — (*After doing as his father directs him.*) The quicksilver will not rise higher than it was before; it stands at 50°.

MR. P. — Now, then, apply the bulb to the

knob of the poker, and mark whether the mercury falls.

Robert. — To be sure it will. (*Robert holds the poker in one hand, and with the other brings the thermometer close to the knob. After holding it in this manner a minute, he looks at his father quite astonished.*)

Mr. P. — You seem surprised: — how much has the thermometer fallen?

Robert. — Not at all! and instead of falling, as it ought to do — for I am sure the poker feels very cold — the quicksilver is beginning to rise. It is now at 52°, and yet the poker seems as cold as ever.

Mr. P. — Remove the thermometer from the poker, again wrap wool round the bulb, and see what follows.

Robert. — Why, the quicksilver has fallen to 50°! I'll never trust to a thermometer again; for, though the wool is warm and the poker cold, it would have me believe that the steel is warmer than the wool.

Mr. P. — Do not be so hasty in condemning the thermometer, but rather doubt your own feelings.

Frederick. — But surely, father, the wool is warmer than the cold poker?

Mr. P. — The thermometer tells us that it is not; and why should we doubt its accuracy in this case, when we know that in all others the mercury in the bulb expands, and rises up the tube,

when we expose it to heat, and that it contracts with cold? I cannot, therefore, suppose it acts differently now, but must believe that the poker was hotter than the wool.

Robert. — But it has no feeling, as we have; and where is the use of feeling, if we cannot tell heat from cold better than a senseless thing?

Mr. P. — It is true the thermometer has no feeling, and therefore is less likely to err. Our feelings are acted upon by so many circumstances, that it is often difficult to judge, from feeling alone, as to the actual heat of any substance.

Robert. — I don't think I should be so foolish as not to tell hot from cold, neither.

Mr. P. — As you appear so confident in your own judgment, we will put it to the test. Fetch three basons, and two jugs full of water, one cold from the pump, the other hot. (*Robert and Frederick bring in the three basons and the jugs of water.*)

Harriet. — I am very curious to see this experiment; and I should laugh heartily at Robert, if he could not tell hot from cold after all.

Mr. P. — Well, my dear, we shall see. Now, you observe, I have poured hot water into the first bason, cold water into the third, and a mixture of both into the middle bason. The thermometer stands in the first at 120°, in the third bason at 40°, and in the middle one at 70°. Robert, put your hand into the hot water, and, Frederick, put yours into the bason of cold water.

Robert. — Well, I am sure this is hot; I can hardly bear it.

Frederick. — And I think there can be no doubt that this is very cold.

Mr. P. — Now take your hands out of those basons, plunge them quickly into the middle one, and tell me how the water in that feels.

Robert. — Oh! this is quite cold.

Frederick. — To me it feels very warm.

Harriet. — Which of them is right, papa?

Mr. P. — Frederick is right in saying the water feels to him warm, therefore Robert must be wrong when he says positively it is quite cold. But we shall, perhaps, hear him contradict himself. Now, then, my boys, change places; and, Robert, put your hand into the cold water, and, Frederick, put yours into the hot.

Robert. — Well, I cannot be mistaken now; this feels almost as cold as ice.

Mr. P. — Take out your hands, and put them into the middle bason, as before. Now, Robert, warm or cold?

Robert. — Why, it is very warm, indeed.

Harriet. — Warm! — why, you just now said it was cold! I did not think you "could ever be so foolish as not to know hot from cold!" Ha, ha, ha!

Robert. — I cannot think it is the same: it must have got warmed since I felt it before.

Frederick. — To me it feels cold. I wish you would explain the cause of this to us, father.

Mr. P. — Yes, I will, presently; but I must first convince your brother that his feelings may not only lead him into error, but may be contradictory at the same time; for he appears not yet perfectly satisfied. Robert, put your right hand into the hot water, and your left into the cold, and then plunge them at the same moment into the middle bason. (*Robert, after holding one hand in the cold water, and the other in the hot for about a minute, puts them together into the middle bason.*) Now let us know whether it is really hot or cold.

Robert. — To my right hand it feels cold, and to my left hand quite warm.

Harriet. — Well, Robert, this is worse and worse! Cold one minute, hot the next, and then both hot and cold at the same time! I have heard of a person blowing hot at one time, and cold at another, but you blow both at once: ha, ha, ha!

Robert. — I am sure it is so; and you may try yourself, Harriet, if it is not.

Mr. P. — I have no doubt the water feels, as you say, warm to one hand, and cold to the other; but, as it cannot be both at the same time, tell us whether it is warm or cold.

Robert. — Why, it is warm compared with the cold water, and cold compared with the hot.

Mr. P. — Very good; but still you do not tell us, as you were sure you could, whether it is hot or cold.

Robert. — It feels both.

Mr. P. — Then you must admit that your feelings, of which you boasted, will not enable you to judge excepting by comparison; and that the same degree of heat may appear hot and cold at the same time, under different circumstances.

Robert. — It does seem so, indeed.

Mr. P. — Well, then, since you have had reason to doubt the accuracy of your feelings in this experiment, I hope you will again trust to the thermometer, and believe it was correct in representing the poker to be hotter than the wool.

Robert. — The thermometer was right as to the water; but I cannot think how it could be right as to the poker and wool.

Harriet. — Do, dear papa, tell us how that was.

Mr. P. — I will now explain the mystery. Every inanimate substance, exposed to the same temperature, possesses, usually, the same degree of sensible heat; and the difference in warmth to the touch depends upon their different powers of conducting heat, — which was the subject of our conversation yesterday. The human body, being generally warmer than surrounding objects, is continually parting with its heat to them. Now, when any thing that has the power of conducting heat quickly touches our bodies, the heat is drawn rapidly from the part touched, and produces the sensation of cold. Therefore the poker, though really possessing the same degree of heat as the wool, feels very much colder, because it has the

power of drawing the heat from the hand much more rapidly than the wool.

FREDERICK. — But the thermometer did not show this.

MR. P. — No, my dear, for the mercury was of the same temperature as the wool and the poker; therefore, would not be affected by their different powers of conducting heat. But if you make the mercury in the bulb hot, you will find that it will descend much more rapidly when surrounded by cold metal, than it will if wrapped in wool: that is, the heat will be drawn from it more quickly by the metal than by the wool; and, if the instrument were capable of sensation, it would feel colder with the metal than with the woollen covering.

ROBERT. — Ay, but the thermometer not only did not fall, but it rose two degrees after being held to the poker. How could this happen?

HARRIET. — Yes, papa; that made the thing so very odd. I should like to know that.

MR. P. — The cause of the mercury rising is easily explained. As Robert held the poker in his hand whilst he applied the bulb of the thermometer to it, the cold he felt was produced by the metal drawing the heat rapidly from him, and becoming itself warmer; which increase of heat was shown by the rise of the mercury.

HARRIET. — So that the faster the poker got hot, the more positive Robert would have been

that it was cold. I should never have thought of that.

Mr. P. — Let us return to the point from whence we started: — Can you now tell me why woollens and furs are preferred for clothing in cold weather?

Frederick. — It must be because they are bad conductors of heat, and therefore prevent the warmth of the body from being taken away, as it would be by substances that were better conductors.

Mr. P. — Very well explained, Frederick.

Robert. — Yes, I understand that; but as air is a bad conductor of itself, as you told us yesterday, father, why should we require any clothing at all to keep ourselves warm?

Mr. P. — That is, indeed, a very natural enquiry, and I am glad you have asked the question, Robert, as it shows you have a spirit of research worthy a young philosopher. I think, however, we have had enough of this subject to-day, and it will serve us for our conversation to-morrow.

CONVERSATION III.

COLD PRODUCED BY WIND.

Robert. — Now, father, will you tell us why the air feels so much colder than wool, which, if it is a bad conductor of heat, it ought not to do?

Mr. P. — In the first place, before I explain the cause, let us perceive the effect; and for this purpose the bellows will do very well. Robert, hold the back of your hand, that Frederick may blow upon it with the bellows. (*Frederick blows with the bellows against the back of Robert's hand.*) I dare say the wind feels cold.

Robert. — Yes, very cold indeed.

Mr. P. — Now, Frederick, let the wind from the bellows blow upon the bulb of the thermometer, and see if it produces any change.

Frederick. — (*After blowing on the thermometer.*) Not in the least.

Robert. If I had not been convinced yesterday that my feelings might deceive me, I should certainly say the thermometer was not to be depended upon.

Mr. P. — I am glad you have become less

confident; and, after the experience of yesterday, I trust you will not again put your feelings of cold against the decision of the thermometer, which now informs us that the wind from the bellows and the air of the room are of the same degree of heat.

Robert. — Then why do they feel so different?

Mr. P. — The cold produced by wind is occasioned entirely by the motion of the air, which thus presents a constantly changing surface to attract the heat from the body, — as I mentioned to you in our conversation on the diffusion of heat. The air, being a bad conductor, would, if at perfect rest, draw the heat from the human body very slowly. In that case the air nearest the surface of our bodies would soon become nearly of the same temperature as ourselves; and, as it would part with its heat to the surrounding portions of air but very gradually, we should feel as hot as if covered with the warmest clothing.

Robert. — Then why is clothing necessary to keep ourselves warm when there is no wind?

Mr. P. —Because the air is never at rest. The motions of our limbs, the movements of our bodies, and our breathing, all tend to expose us every moment to a fresh surface of cold air, independently of other causes. And though heat passes with difficulty from one particle of air to another, yet each particle, when brought into close contact with a heated body, absorbs heat from it; and the more quickly these particles are changed, the

faster is the heat taken away, and the greater will be the feeling of cold.

Frederick. — It is in the same way, I suppose, that things are cooled by blowing upon them?

Mr. P. —Exactly so. A rapid change of air always produces a feeling of cold, when the temperature of the atmosphere is lower than that of our bodies. Even the thermometer may be made to exhibit signs of being affected by a current of air, as I can show you by an easy experiment.

Harriet. — I should like to see that senseless thing made to feel cold by the wind.

Mr. P. — Hold the bulb of the thermometer, Robert, in hot water till the mercury rises to 120°, and then take it out and notice how long it is in falling to 80°.

Robert. — (*Looking at his watch with the thermometer in his hand.*) Just three minutes.

Mr. P. — Raise the mercury to 120° again, and be you ready, Frederick, with the bellows, to blow upon the bulb as soon as Robert takes it out of the water.

Robert. — (*Holding the thermometer, whilst his brother blows as fast as he can with the bellows.*) The quicksilver has fallen to 80° in one minute only.

Mr. P. — You would find, on repeating the same experiment with the bulb well wrapped in wool, that it would then resist the action of the bellows much longer; for the wool, besides being

a bad conductor itself, would prevent the air, nearer the bulb, from being so quickly changed by the bellows.

FREDERICK. — Do our clothes keep us warm in this way, by protecting us from the wind?

MR. P. — Yes, my dear; and this is the principal use of the thick clothing we put on in winter; for if we could enclose ourselves in a case perfectly air-tight, a thin flannel covering might keep us as warm as the thickest great coats. The most effectual mode of keeping out the wind, and preserving the heat of the body, is that adopted by the inhabitants of the polar regions, who wear the skins of animals turned inside out. By this means the dried skin acts as a screen to prevent the wind from penetrating; and as the fur contains a quantity of air between its fibres, that part of the body so covered is thus enclosed in a case of confined air.

FREDERICK. — But if the air were hotter than the body, would the wind feel cold?

MR. P. — No, Frederick. When the temperature of the air is greater than that of the body, the wind feels insufferably hot. The hot winds from the deserts of Arabia and Africa often destroy the lives of animals exposed to them; and the natives, who know when to expect these winds, shut themselves up in their tents to be out of their scorching effects.

HARRIET. — I should like to feel a hot wind.

Robert. — I can't think how it is possible for the wind to be hot.

Mr. P. — I believe I can satisfy your doubts and Harriet's curiosity very shortly. Frederick, light the Argand lamp, —put on the glass chimney,—and then give me the bellows. Now, you observe, that I have closed the nozle of the bellows, and that I hold the large opening, which admits the air, at a little distance from the chimney of the lamp, so that when I separate the legs slowly, the hot air, rising from the lamp, is drawn in. I must expel the air and fill the bellows a few times, to heat the interior, and drive out the cold air. Now, Harriet and Robert, hold your hands and feel the wind as it is forced out of the nozle.

Robert. — It is quite hot!

Harriet. — Yes, so it is! I declare the bellows can blow hot and cold as well as you, Robert: ha, ha!

Frederick. — I suppose the cold produced by fanning is owing to the motion given to the air by the fan.

Mr. P. — Yes, it is. By the action of the fan, fresh particles of air are driven rapidly against the face, and thereby carry away a greater portion of its heat than before. You may frequently hear ladies, who are fanning themselves, say, that they are "cooling the air," though, in reality, every motion of the fan gives additional heat to the air, by causing it to abstract a greater quantity from the body.

Harriet. — That is very curious. I always thought it made the air cooler.

Mr. P. — Fanning makes the face cooler, my dear, but it does so only by carrying off its heat more rapidly to the air.

Robert. — But fans are generally used in hot rooms and in warm weather, when the air is already so hot that, if it were not cooled by the fan, it would be like a hot wind.

Mr. P. — The air is not, in the hottest room, nor in the warmest weather, in this country, ever so hot as the human body. The natural heat of the body is 98°, whilst our hottest summer's day seldom exceeds 84° in the shade. The air, however, is never heated so high as the temperature indicated by the thermometer, for that instrument is acted upon by the heat reflected from surrounding objects; but even if we allow the air to contain 84° of sensible heat, it would still be considerably cooler than the body, and a strong current, by greatly increasing its conducting power, would feel very cold.

Harriet. — Then it seems that ladies, who fancy they are cooling the air by fanning, make the same mistake that Robert did, when he thought the poker was so very cold because it was getting hotter.

Mr. P. — Exactly so. I trust you now understand the cause of the air feeling generally cold; and why the sensation of cold is increased on its being put into rapid motion. When I speak of

cold, however, you must not imagine that I mean a total absence of heat; and still less, that cold is an absolute property, capable of entering into different substances, like heat. After what you have heard, you may, perhaps, be prepared to learn, that there is no such thing as absolute cold.

ROBERT. — Not such a thing as cold! Well, father, you may be right about the poker and wool; but as to cold, nobody can be mistaken that can feel.

MR. P. — What, Robert! do you still place such reliance on your feelings; and have you so soon forgotten how they failed you, when put to the test with the hot and cold water?

ROBERT. — No, I have not forgotten that; but to suppose there is no such thing as cold, one must forget to feel.

HARRIET. — I cannot help thinking as Robert does about cold. Do, pray, papa, tell us what it is you mean.

MR. P. — I will do so, my dear, to-morrow.

CONVERSATION IV.

COLD.

(FREDERICK, ROBERT, *and* HARRIET *warming their Hands at the Fire. The Morning very cold and frosty, and a heavy Fall of Snow. Mr.* POWELL *enters the Room.*)

HARRIET. — PAPA, I am glad you are come at last; for now that the ground is covered with snow, and it is freezing so hard as almost to freeze us into icicles, do you still say it is not cold?

MR. P. — It *feels* intensely cold, my love; but our feelings, as Robert knows, may be mistaken; and I still say, and hope to prove to you, that there is no such thing as cold.

FREDERICK. — What is it, then, that makes the water freeze, and that makes us all feel so cold to-day?

MR. P. — The short and correct answer to that question is, that the air is not so hot to-day as it was yesterday.

Robert. — But it was not hot yesterday, by any means; it was only not so cold as it is now.

Mr. P. — The air did not appear to us to contain any heat, because our bodies were so much hotter than the air, and, consequently, it deprived us of heat: but it certainly contained more sensible heat than the air does to-day; and I think I can make you aware that this frosty day is not without heat.

Harriet. — Do, dear papa, show us how, for I am now shivering with cold.

Robert. — With want of heat you should say, Harriet — ha, ha, ha!

Mr. P. — Yes, Robert, ridiculous as it may sound, that is correct. Even snow feels warm when compared with substances still colder, as I can convince you if you bring me a basin full of snow, and a cup full of salt. (Robert *brings in the snow and salt, as required.*) Now put the thermometer into the snow, and see the temperature.

Robert. — It is 32°.

Mr. P. — That is just the freezing point; and it is, therefore, as cold as ice. I will now put part of the snow into another basin, and mix the salt with it in the proportion of one part of salt to two of snow: observe, the mixture is become liquid. Robert, put your hand into it.

Robert. — (*Putting his hand in the water.*) Oh! oh! I cannot bear it any longer.

Mr. P. — Take your hand out, then, and put it into the snow, and tell us how that feels.

Robert. — Why, compared with the other, it is warm.

Mr. P. — Harriet, put your hand into the snow, that Robert says feels warm, and let us know what you think of it.

Harriet. — Oh! it is very, very cold.

Mr. P. — Nay, Harriet, it cannot be really cold and warm at the same time. Robert says the snow is warm, compared with the mixture of snow and salt, and the thermometer will agree with him. (*Mr.* Powell *puts the thermometer bulb into the basin of snow and salt.*) See, the mercury falls 32° below the freezing point; and when I remove it to the snow it will rise to 32°; therefore Robert must be right in saying the snow is warm. It *felt* cold to you, Harriet, because the air of the room is so much warmer than snow; but Robert, having previously immersed his hand in a mixture so much colder, was capable of feeling the heat of the snow.

Robert. — Yes, father; but the mixture of snow and salt must be cold, for the thermometer sunk down to nothing, and there cold must begin.

Mr. P. — It was, indeed, so considered by Fahrenheit, the maker of the thermometer generally used in England; but recent observations have proved that opinion to be wrong. The thermometer may be made to fall 50° below the nothing in Fahrenheit's scale by a mixture of snow and potash; and, compared with this, the mixture of snow and salt would be very perceptibly

warm. It would be dangerous, however, to expose the flesh suddenly to contact with a mixture of so low a degree of temperature; but the thermometer would show that the snow and salt contained heat, by its rising rapidly in that mixture when taken from the snow and potash.

Frederick. — How cold is it in the coldest part of the world?

Mr. P. — The temperature near the poles we cannot ascertain, as the solid masses of ice that constantly cover that part of the globe prevent ships from approaching within several hundreds of miles. The voyagers who have approached the nearest to the poles have found the cold so intense as to become dangerous, notwithstanding all the precautions they could take. Even at Hudson's Bay, which is an English settlement, in North America, the thermometer is frequently as low as 50° less than nothing; compared with which our present temperature, that you think so cold, would be like the hottest day in summer.

Harriet. — How can the poor people manage to keep alive there?

Mr. P. — They wrap themselves in furs, and endeavour, as much as possible, to avoid exposing any part of their bodies to the air. The snow, too, with which the ground is covered, helps to keep their cabins warm.

Harriet. — Snow make them warm! Well, that is very odd!

Mr. P. — Yes, my dear; the air confined be-

tween the flakes or crystals of snow being a very slow conductor of heat from the body, the inhabitants find that, when rolled up in a blanket, and burrowed under the snow, they are warmer than in their beds. The temperature is so low in that part of the world, that if water be thrown into the air it will be ice when it falls down; and it is even stated, that the moisture of the breath is sometimes frozen, and falls to the earth like a shower of snow.

Harriet. — What, breathe a shower of snow! Well, I shall soon believe that Baron Munchausen's words were really frozen as they came out of his mouth.

Robert. — And that they chattered away in the thaw? — ha, ha!

Mr. P. — After having shown you that what feels to us intensely cold, really contains heat, and is absolutely warm compared with colder temperatures, I trust your confidence in the existence of cold is shaken.

Frederick. — But if there be no such thing as cold, I suppose there must be a point at which there is no heat; and how low must the thermometer fall when all the heat is taken away?

Mr. P. — There is, no doubt, a point at which all bodies would be deprived of heat; but that point has never been ascertained. The lowest temperature hitherto produced is 100° less than zero, or 132° below the freezing point. Brandy freezes at 7° below zero; mercury becomes solid,

like other metals, at 39°, and ether is congealed at 46° below zero: it is supposed that even the air we breathe would become a solid mass if the temperature could be sufficiently reduced.

Harriet. — Then Baron Munchausen's words might have been frozen, and he may be right after all!

Mr. P. — If you can conceive it possible for a man to live when the air is a solid mass around him, his words would indeed be frozen as they came out of his mouth.

Robert. — But if it were possible to take away all the heat from a thing it must be cold then.

Mr. P. — No, Robert, your conclusion is by no means correct. It does not follow, as a matter of course, that when one property is taken from a body, that another, and opposite one, must exist and enter into it. I think I have convinced you, that, even when the temperature is so low as to deprive human beings of life, the air contains heat; therefore, if that degree of temperature be not cold, we have no reason to suppose such a property as *cold* exists. Persons, naturally enough, imagine all negative properties to have a positive existence; which opinion, however, philosophy has proved to be erroneous: but from custom, and for general convenience in conversation, the words which express the negative quality are used, even by those who do not attach any positive meaning to them. Thus, cold, dulness, darkness, and many other expressions of the kind, are commonly used,

though only intended to signify a deficiency of heat, of brightness, or of light, &c.

FREDERICK. — But would it not be better to call things by their right names? for if we know there is no such thing as cold, why should we talk as if there were?

MR. P. — I agree with you, Frederick, that the use of words which convey a wrong idea of the intended meaning is a bad practice, but it is a difficult one to alter. Even men of undoubted science would shrink from the imputation of learned affectation, which such a departure from generally received expressions would bring upon them; and whilst they refuse to sanction such an alteration in established modes of expression, it would be great presumption in others to attempt to introduce a change in this respect. Any kind of affectation is, at the best, ridiculous; but an affectation of learning, especially in young persons, is sure to excite the dislike as well as the ridicule of every one. I trust, my dear children, I shall never observe this affectation in you, for I had rather you should remain ignorant than that you should pretend to be learned.

CONVERSATION V.

EXPANSION BY HEAT.

FREDERICK. — WHAT a cold morning this is, father! the thermometer is 6° below the freezing point.

HARRIET. — I have been puzzled, papa, to imagine how the thermometer can tell when it is hot and when cold, as it cannot feel.

MR. P. — It is a question that I dare say has puzzled many older heads than yours, Harriet; and as we have made so much use of the thermometer lately, it will be advisable to make you understand the principle which regulates the rise and fall of the mercury in the tube. It depends upon the expansion which the quicksilver undergoes by heat, and its contraction when the heat is removed.

HARRIET. — Does heat make the same quantity of quicksilver really larger than it was before?

MR. P. — Yes, that is its effect, as the thermometer itself might inform you. But, lest you should imagine there is any hidden virtue in the

frame and bulb, you shall see the same effect produced on mercury in a straight tube. I will put into this tube an ounce of mercury, and make a mark on the glass at the point it reaches in the tube. I will now immerse it in hot water, and observe the effect of the heat.

FREDERICK. — The quicksilver has risen above the mark already; I see it rising very distinctly.

MR. P. — As it now occupies more space in the tube, you must be convinced that it has increased in bulk.

FREDERICK. — Does it weigh more now than it did before?

ROBERT. — Of course, a larger quantity of quicksilver must weigh heavier than a smaller.

MR. P. — Weigh it yourself, then, Robert, and tell us how much weight it has gained.

ROBERT. — (*Weighing the mercury.*) It weighs exactly an ounce.

HARRIET. — Then it is no heavier than when first put into the tube. Is that as it should be, papa?

MR. P. — Yes, my love. Robert's position that equal bulks of the same thing must always weigh the same, will not hold good, as he must now perceive.

ROBERT. — But something must have got into the quicksilver to make it larger than it was before, and that something must, I think, make it heavier.

MR. P. — The "something" you speak of is

heat, which is, indeed, supposed to be a material substance, but philosophers have not yet been able to discover that it has any weight. Heat possesses the property of expanding all substances; and it is supposed to do this by surrounding the minute particles of which the substances are composed, and thus separating them farther from each other.

FREDERICK. — Then I suppose the quicksilver must be really lighter when made hot than it is when cold.

MR. P. — Yes, the weight of the *same quantity* of any substance is diminished in proportion to the expansion. Thus, if ten inches of mercury be expanded to eleven inches, the specific gravity will be nearly one tenth less than before; that is, eleven inches of the expanded mercury will weigh no more than the ten inches before expansion.

HARRIET. — But, papa, how can the bulb of the thermometer be filled with quicksilver through so small a tube as it appears to be?

MR. P. — I will show you, my dear, in a moment. The difficulty, though seemingly great, is soon overcome. (*Mr.* POWELL *fetches from his cabinet an empty thermometer tube.*) The aperture of this tube is so small, that it might be considered impossible to fill the bulb at the end.

HARRIET. — I can scarcely see the opening. I am quite curious to know how you will manage to pour the quicksilver through it.

MR. P. — I shall make the mercury run into the

tube without the least trouble. (*Mr.* Powell *lights a candle, and holds the bulb near to the flame.*) I have now heated the bulb sufficiently, and will plunge the open end of the tube into this cup of mercury. Look at the tube as the bulb cools.

Harriet. — The quicksilver is running up the tube by itself, and is entering the bulb. How very strange!

Mr. P. — Having now got the bulb nearly half full, I will hold it again to the candle till the mercury boils, and, on again plunging the tube into the cup, the bulb will be filled. (*Mr.* Powell *fills the bulb in the manner described, at which the children seem greatly astonished.*)

Frederick. — Do tell us, father, what is the cause of the quicksilver running up the tube.

Mr. P. — Yes, my dear; and the more readily, as it affords us another example of the expansion caused by heat. When I held the empty bulb to the candle, the heat expanded the air, and drove part of it through the tube. After I had placed the tube in the cup of mercury, the air in the bulb, on becoming cool, contracted, and, as the mercury prevented the external air from rushing in to occupy its former space, the liquid metal was forced up to supply its place. A more perfect vacuum was afterwards produced by the condensation of the vapour of the boiling mercury, and the whole bulb was filled.

Robert. — Then air expands by heat, as well as quicksilver.

Mr. P. — Yes, Robert; not only quicksilver and air, but every substance, visible or invisible, is expanded by heat. The expansion of liquids and air is, indeed, greater than that of solid bodies; but the hardest rocks and metals are also subject to the expansive power of heat.

Robert. — How can we tell that the air is expanded by heat?

Mr. P. — The experiment already shown you, with the thermometer bulb, is a conclusive proof that it is so; but the expansion may be rendered visible by the inflation of a fire balloon.

Harriet. — Do show us that, papa; balloons are such curious things.

Mr. P. — I am glad I can gratify your curiosity, and exemplify an interesting law of nature at the same time, Harriet. (*Mr.* Powell *brings from his laboratory a small fire balloon.*) This balloon is made of silver paper perfectly air-tight, excepting at the bottom, where there is an opening and a small iron-wire car to hold the combustibles by which it is to be inflated. I shall put into the car cotton wool steeped in spirits of wine. The balloon is at present, you perceive, much collapsed, and looks shrivelled. Robert, apply a piece of lighted paper to the wool, as I hold the balloon, and notice the effect.

(Robert *sets fire to the spirits of wine, and in a short time the sides of the balloon begin to expand.*)

Frederick. — The balloon begins to move, as if it were being blown out like a bladder.

HARRIET. — Its sides are now on the full stretch, and it seems quite swelled out.

MR. P. — The "swelling out" is occasioned by the expansion of the air inside, which, owing to its being kept in an expanded state by the heat of the burning spirits, is become lighter than the air of the room, and when I remove my hand, the balloon will ascend. (*Mr.* POWELL *permits the balloon to rise to the top of the room.*)

HARRIET. — How very pretty it looks, rising up without any one touching it!

FREDERICK. — I suppose, then, father, that air, when heated, becomes lighter than before, in the same manner as the hot quicksilver did, because the quantity of it is increased without any additional weight.

MR. P. — Exactly so. But look! the spirits are nearly burnt out, and the sides of the balloon begin to collapse, as the heat is not sufficient to expand the air. It is now falling to the ground. This experiment shows, in the most striking manner, the effect of heat in the expansion of air. The ascent of smoke up chimneys is owing to this effect of heat.

FREDERICK. — How is that, father?

MR. P. — The heat of the fire expands and rarefies the air in the chimney, and as it is thus made lighter than the external atmosphere, it rises. Its place is supplied by fresh air from below, which is heated in the same manner. The whole chimney thus becomes filled with a column of air

much lighter than a column of the atmosphere of the same height, and it therefore issues rapidly from the top, whilst the air below rushes to the fire-place.

FREDERICK. — Then the draught of a tall chimney should be greater than that of a short one, as the column of light air must be higher.

MR. P. — That is, generally, the case, provided the fire is sufficiently large to keep the whole column heated.

ROBERT. — But the chimneys of very high houses will sometimes smoke, which they ought not to do if the draught depends upon the height of the column of light air.

MR. P. — Many causes may tend to make even a very tall chimney smoke. Chimneys are often so badly constructed as either to prevent the air from becoming sufficiently heated, or to obstruct its free passage upwards. For instance, if the opening above the grate be very large, it will admit more air than the fire can heat, and the column in the chimney will not be sufficiently light to ascend as it ought to do; or, if there be many irregularities in the chimney itself, or any accidental obstruction, the progress of the air and smoke will be partially stopped, and part of the smoke will enter the room.

HARRIET. — If the fire is the cause of the draught, what is the use of putting those things on the tops of chimneys to prevent their smoking?

MR. P. — They are only intended to act as

screens against the wind, and not to increase the draught; for if the wind blow into a chimney, it has the effect of obstructing the current of air from issuing out at the top, and of driving it down.

Frederick. — I understand now why it is that chimneys generally smoke in a high wind.

Harriet. — I have seen, papa, a piece of paper cut and painted like a snake, hanging with its head downwards, and supported with a wire by its tail over a candle, that turned round and round as if it were alive: was its turning round owing to the expansion of the air by the candle?

Mr. P. — Yes, my dear. The heat of the candle rarefies the air, and causes it to rise, producing an upward current. This current of air, striking against the oblique sides of the paper snake, gives it a rotary motion, and the paper will continue turning as long as the candle produces the current.

Frederick. — Do smoke-jacks in chimneys turn round from the same cause?

Mr. P. — Yes; the current of air up the chimney strikes against the oblique vanes of a wheel fixed there with sufficient force to turn it round, and put in motion all the machinery of the smoke-jack. Many natural phenomena are produced by the action of heat in expanding, and consequently lessening the weight of, the air. The winds are caused by this effect, as I shall explain to you more particularly on some future occasion. I will conclude this morning's conversation by mentioning to you a few instances of the expansion

of other substances by the same means. This knitting needle will answer our purpose exceedingly well to show the expansion of metals. You see that it is just large enough to enter the ward of this key: I will put it into the fire to get hot, and you shall try if it will pass through then. Here, Robert, take hold of the needle with this piece of paper, and try to put it into the ward.

ROBERT.—(*Trying to get the knitting needle into the ward.*) It will not enter the ward now; it has grown larger than it was.

MR. P.—Yes; it is expanded by the heat.

ROBERT.—You told us, father, that the expansion of quicksilver by heat was owing to the particles of the quicksilver being separated by the heat getting between and surrounding them: how is it that heat expands other metals whose particles do not move at all?

MR. P.—The particles of solid metals, indeed, appear to be immovable; but they are supposed to be continually in motion, though they are so minutely small, that their motions are imperceptible. Heat, it is concluded, operates in the same way upon solid substances as upon liquids, by separating their particles or atoms; and that some motion must have taken place in the metal of the knitting needle is evident from the fact of its being expanded in all directions.

FREDERICK.—Are all metals expanded as much by heat as iron is?

MR. P.—No: the metals, and nearly all sub-

stances, vary in the degrees of their expansion; but it is a general rule that bodies expand by heat, and contract with cold. The most remarkable exception to this rule is water.

FREDERICK. — Is not water expanded by heat, father?

MR. P. — Yes; it is expanded by all temperatures above 42°; but on being cooled below that point it begins to expand again, and the expansion increases as the temperature is reduced below 42°, in the same proportion as it increases when it is heated above that point.

HARRIET. — That is very singular: what can be the reason of it?

MR. P. — It is not known in what manner the abstraction of heat from water causes its expansion below 42°; but, ignorant as we are of its cause, we know sufficient to excite our admiration of the beneficent provision of Nature in making this exception to the general laws which regulate other bodies. If water were contracted as it is deprived of heat, like other substances, the ice, as it was formed, would sink to the bottom of the water, a fresh quantity would supply its place, and, being frozen, sink as before; and in a continued frost the whole of our rivers and northern oceans would become solid masses of ice. In consequence of this singular exception, however, as soon as the water is cooled below 42°, it swims on the surface, and protects the water below from being exposed to the freezing influence of the atmosphere.

Robert. — But the water immediately underneath must touch the ice on the top, and therefore become as cold as it is.

Mr. P. — It does so to a certain extent, and that occasions the thickness of the ice in long continued frosts; but water is so slow a conductor of heat, that it requires a length of time to abstract the heat from the water below, so long as it remains stationary there by its superior weight.

Robert. — Then, father, we should have had no skating, if water got heavier as it became colder, until the whole water in the ponds were frozen.

Mr. P. — No, indeed, Robert, you would not; for the ice would be at the bottom.

Frederick. — Nor any fishing either, for all the fish would be killed by the first hard frost.

CONVERSATION VI.

BOILING.

Harriet. — Oh, look, papa! the kettle is boiling over. I was afraid I should have been scalded.

Mr. P. — Have you ever thought what it is that causes the water in the kettle to boil over in this way; or of the cause of its boiling at all?

Robert. — It does not require much thought, I suppose, to tell that: it is the fire.

Mr. P. — We should not be much wiser by that answer, Robert. The fire makes the water boil, but how?

Robert. — By making it hot.

Mr. P. — We are no nearer to an explanation yet. The question is, how does heat produce the effect?

Robert. — That I cannot tell; but I know that water will not boil without fire.

Mr. P. — Do not be too positive, Robert. What would you say to a proposal for boiling water by cold?

Robert. — That it is impossible.

Mr. P. — I will convince you to the contrary.

HARRIET. — Can you, papa? I am all curiosity to see how.

MR. P. — Bring me a thin bottle, or decanter, and I will half fill it with water from the kettle. (ROBERT *fetches his father a decanter, into which Mr.* POWELL *pours boiling water, after first warming the decanter to prevent it from cracking, and then he corks it.*) You perceive the water is perfectly motionless, and does not boil now. Robert, bring me a cloth dipped in the coldest water you can find — it is to make the water boil.

ROBERT. — You must be joking, father.

MR. P. — Bring the cloth, and you shall see. (ROBERT *goes for the wet cloth, and brings it to Mr.* POWELL.) I will put it to the top of the bottle, which is full of steam; now look, Robert, at the water.

ROBERT. — Why, it is really boiling as briskly as if it were on the fire.

MR. P. — You see that when I remove the cold cloth the water ceases to boil; and that when I cover the neck with the cloth, it boils again.

FREDERICK. — What is the cause of its doing so, father?

MR. P. — Before I explain the cause of this phenomenon, I must return to the original question; — What makes water boil when put on the fire?

ROBERT. — I do not know what to say; I will thank you to tell me, father.

MR. P. — When water is placed in the kettle,

over the fire, a portion of heat is communicated to it every moment, and the water at length becomes heated to the boiling point, that is, to 212° of Fahrenheit's thermometer. At this point the water nearest the bottom of the kettle is converted into steam, which, as soon as it is formed, rises rapidly to the surface in large bubbles, causing great commotion in the water; and, when the fire is hot, the steam is formed so quickly, that the bubbles force part of the water above the top of the kettle, causing it to boil over.

HARRIET. — But the steam begins to form some time before the water boils.

MR. P. — Yes, my dear, but very slowly; for the elastic force of steam does not become sufficiently strong to balance the pressure of the atmosphere until the water is heated to about 212°; and the steam will not form at the bottom until its force is equal to the atmospheric pressure.

FREDERICK. — How does the pressure of the atmosphere prevent the steam from rising?

MR. P. — In the same way as a weight placed upon an elastic body presses it down, and prevents it from rising. Water, when possessing sufficient heat to keep it in a liquid state, has a strong tendency to evaporate, and, were it not for the pressure on its surface, would be rapidly dissipated into an elastic vapour. The force of the vapour of water at 32° is equal to one ounce and a half on every square inch; and as the water is heated the force of the vapour increases, until, at 212°, it is equal to the

pressure of the atmosphere, that is, fifteen pounds on every square inch; and the steam then rises to the surface as fast as it is formed. After water is heated to its boiling point, it cannot be made any hotter so long as it is exposed to the air, however hot the fire may be; for the heat, as fast as it enters the water, is conveyed away by the steam. If water be heated under a greater pressure than that of the atmosphere, the temperature may be raised considerably higher than 212°, without boiling; and, on the contrary, if the pressure of the atmosphere be removed, water will boil at 72°. It has been ascertained that fluids generally boil in a vacuum at a temperature 140° less than under the pressure of the atmosphere.

Harriet. — But now, papa, tell us how it was that the water in the bottle boiled by cold?

Mr. P. — When I applied the cold cloth to the upper part of the bottle the steam at the top became condensed into water, owing to the absorption of its heat by the cloth, and produced a partial vacuum in the bottle. Part of the pressure of the atmosphere being thus removed, the elastic force of the steam formed by the hot water became more than equal to the remaining atmospheric pressure, and therefore it rose in bubbles to the surface. When I removed the cold cloth, the steam ceased to be condensed, and, therefore, shortly pressed upon the hot water with a force equal to the elastic power of the steam it was capable of forming, and prevented the steam from

rising; but on re-applying the cold cloth, the same effect was repeated, from the same cause.

ROBERT.—Ay, but the water was nearly boiling hot to begin with: you cannot make liquids boil without heating them first.

MR. P.—It is true that water will not boil, even under the receiver of the air-pump, till it is heated to 72°; but ether, which is a more volatile fluid, can be made to boil without being heated.

FREDERICK.—I should like to see it very much.

MR. P.—You shall, my dear; but for this experiment we shall require the air-pump. I shall show you that ether may boil even when it is cold enough to freeze water; and, what is still more extraordinary, that its boiling will cause the water to freeze.

HARRIET.—That will, indeed, be strange.

ROBERT.—Yes, if ether boils with freezing cold, it will be curious.

(*Mr.* POWELL *places the air-pump on the table. Under the receiver he puts a small glass full of ether, and on the top of the ether, and floating on its surface, a watch-glass containing a little water.*)

MR. P.—Having put the ether and the water under the receiver, I will exhaust the air rapidly; now look at the ether.

FREDERICK.—It seems to be boiling away as if there were a fire under it.

ROBERT.—Yes, indeed it is; I cannot help thinking it must be hot.

Mr. P. — I will let in the air, and take off the receiver, that you may feel. Now, Robert, put your finger into the ether, and let us know if it be hot.

Robert. — (*Touching the ether.*) No, it feels quite cold.

Frederick. — And the water in the watch-glass is frozen into a mass of ice! Do explain the cause of this, father.

Mr. P. — After what I have told you respecting the effect of the pressure of the atmosphere on the boiling of fluids, I need not, I suppose, say more about the cause of the ether boiling, than that its vapour is so elastic as to overcome the pressure of the atmosphere when heated to only 90°; and that when the pressure of the atmosphere is removed, the ether becomes very rapidly converted into vapour, even when its temperature is 76° lower than the freezing point.

Frederick. — But what made the water freeze whilst the ether was boiling?

Mr. P. — You must understand, in the first place, that steam and vapour contain a very large quantity of heat, which they abstract from liquids when boiling; and it is owing to the quantity of heat they thus carry away that liquids cannot be heated above their boiling points. This is the cause why water, when placed in an open sauce-pan over a hot fire, cannot become hotter than 212°, though the fire itself is perhaps upwards of 2000°; for the steam deprives the water of the heat as fast as it

is communicated. Thus, in the case of the ether, when the pressure of the air was removed, the vapour into which it was rapidly converted, drew the heat from the ether, and from the water floating on its surface, so quickly, that the temperature of the water was reduced below 32°, and it became frozen.

Frederick. — Do all vapours, whether cold or hot, take heat from bodies in the same way?

Mr. P. — Yes, my dear; and there is reason to believe, that when vapours rise from a comparatively cold surface, they contain really more heat than when the liquids are boiling. It is owing to this absorption of heat by vapour, that we feel such a sensation of cold from wet clothes; as the evaporation of the moisture draws the heat from our bodies, which is carried off by the vapour.

Harriet. — What is the reason, papa, that people do not take cold when wet with sea water so soon as with fresh water?

Mr. P. — The salt contained in sea water prevents the liquid from evaporating so quickly, therefore, the sensation of cold is not so great, because the heat is drawn from the body more gradually. Spirits, on the contrary, evaporate much more rapidly than water, and the cold produced by their evaporation is, consequently, much greater. If, for instance, you drop ether on the back of your hand, it feels extremely cold; and the effect is increased by doing so in the full heat of the sun, as the evaporation then becomes

quicker: indeed, so rapidly is the heat abstracted, that small animals may be frozen to death, in this manner, under the heat of a summer's sun.

Frederick. — Thank you, father, for these interesting explanations, which I hope I shall remember; but I should like to know something more about the nature of steam, which is now made to do every thing. Can you tell us what makes it so strong, as to be able to do the work of horses?

Mr. P. — I will endeavour, my dear, to give you some idea of the subject to-morrow.

CONVERSATION VII.

STEAM AND VAPOUR.

Frederick. — Is the steam we see coming out of the spout of the kettle the same kind as that which works steam engines?

Mr. P. — You are mistaken, my dear, in supposing you *see* the steam, for steam is invisible, like air and most other elastic fluids; but the steam *in* the kettle, which you cannot see, is the same as that employed in working engines.

Robert. — Not see the steam! why, look, father, it is coming from the kettle spout most furiously. I am sure I see it.

Harriet. — And so do I.

Mr. P. — You see a stream of something, resembling a thick mist, issuing from the kettle, but that is not *steam:* that mist consists of minute particles of *water*, into which the steam is condensed as soon as it comes in contact with the air. If you look close to the spout, you will perceive there is a space of about half an inch, between the spout and what you call steam, in which you see nothing — that is steam.

Frederick. — Yes, I see a vacancy between the spout and the steam; yet there must be something there, for the misty steam seems to come from it.

Mr. P. — You observe, that what you call "misty steam" becomes less perceptible as it approaches the spout, because the condensation of the steam does not take place all at once. Near the spout only a partial condensation occurs; but as the steam issues farther into the air it expands, and a larger surface being thus exposed, it is completely condensed.

Frederick. — What is the cause of steam condensing so quickly?

Mr. P. — A large portion of heat is always required to prevent vapour from condensing; and the elasticity, the invisibility, and the great bulk of vapours, compared with liquids, are supposed to be owing to the large quantity of heat they contain. Thus, steam of the temperature of 212°, which equals the elasticity of the air, is rapidly condensed into water when exposed to a lower temperature, because the heat necessary to preserve it in that state of elasticity is then taken from it. The vapour of spirits being more elastic (that is, having a greater attraction for heat,) is not so easily condensed as steam; and ether, indeed, will not remain in a liquid state at a temperature higher than 90°; therefore, in hot climates, ether can exist only as an invisible vapour, unless confined under pressure.

Frederick. — What is the bulk of steam compared with water?

Mr. P. — At the temperature of boiling water, steam occupies 1800 times the space of the water from which it is formed; therefore, a pint of water, when converted into steam, would fill 225 gallons.

Frederick. — But when steam is converted into water again, what becomes of the space it filled?

Mr. P. — If the steam, when confined in an air-tight vessel, be completely condensed, the space it occupied is left vacant; and unless the vessel be strong, the pressure of the atmosphere on the outside would press in the sides. I can show this to be the case by an easy experiment.

Harriet. — I should like to see it, very much.

Mr. P. — Into this moist bladder I put a tea-spoonful of ether, and after squeezing out the air I will tie it up. Now, notice what takes place when I put it into hot water. (*Mr.* Powell *holds the bladder in a basin of hot water, when it almost immediately becomes inflated.*)

Harriet. — It has blown the bladder out.

Mr. P. — Yes; the ether is converted into vapour by the heat, and has filled the bladder. I will now put it into cold water, which will condense it into a liquid again. (*Mr.* Powell *immerses the bladder in cold water.*)

Frederick. — Look, how the bladder shrinks! it seems as if it were alive: what makes it do so?

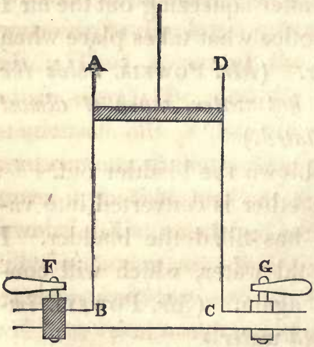
Mr. P.—The ether, as it condenses, leaves a vacuum in the bladder, and the pressure of the atmosphere forces its sides together. Any vessel, if not made strong enough to resist the pressure, would do the same.

Robert.—Would water produce the same effect as the ether.

Mr. P.—Yes, exactly, if it were heated to the boiling point. I used ether because it is changed into vapour by a lower degree of heat, and therefore the experiment could be more readily performed.

Frederick.—It seems a very curious thing that the bulk of steam should be all at once lessened to a mere nothing by cold. Is any use made of this property in the steam engine?

Mr. P.—The whole power produced by many steam engines depends entirely upon it. In the first engine made by the celebrated Mr. Watt, all the power gained depended on the pressure of the atmosphere upon a piston moving in a cylinder, which was forced down by the atmospheric pressure when the steam underneath was condensed. But I shall make the subject more clear by this drawing. In this sec-



tion A B C D represents a large cylinder, one foot or more in diameter, with a moveable piston, fitting tight to the sides of the cylinder. At the bottom there are two openings, B and C, one of which, C, communicates with a vessel containing cold water, to act as a condenser, and the other, B, communicates with the boiler. Now, supposing the cylinder to be filled with steam, and the stop cock, F, communicating with the boiler to be shut, and the stop cock, G, to be opened, the steam will rush along the pipe communicating with the condenser, and be immediately condensed into water, thereby producing a vacuum under the piston, which will then be forced down to the bottom of the cylinder by the pressure of the atmosphere.

ROBERT. — How can the piston be raised up again?

MR. P. — As soon as it arrives at the bottom, the stop cocks are turned, so as to cut off the communication with the condenser, and to let the steam in again from the boiler. The pressure on the piston being thus removed, by the elasticity of the steam underneath, it is raised to the top by a heavy weight placed at the end of a large beam. The motion of the piston and beam, up and down, is thus continued as long as the steam is supplied in proper quantities, and the water in the condenser continues cold enough to condense it.

FREDERICK. — I don't remember to have seen

any weights at the end of the beams of those steam engines I have seen.

Mr. P. — No, my dear; for in Mr. Watt's improved engines he introduced the steam at the top of the piston, as well as underneath, and in that manner produced a vacuum above as well as below it; and the piston in these engines is forced both up and down by the pressure of the steam acting against a vacuum.

Frederick. — Are all steam engines formed upon the principle of making a vacuum by condensing the steam?

Mr. P. — No, they are not. The engines I have described are called *condensing engines,* because their action depends upon the condensation of the steam. The engines now most in use are made to act upon a very different principle, depending upon another property of steam, viz. its elasticity.

Harriet. — What do you mean, papa, by saying steam is elastic?

Mr. P. — By elastic, my dear, I mean the power steam possesses of regaining its original bulk after having been compressed into a smaller compass; and the force it exerts in trying to regain its natural degree of expansion, I call its *elastic power.* It is in the application of this force that the principle of the high-pressure steam engines consists.

Frederick. — How can steam be compressed so as to exert the force that is wanted?

Mr. P. — By heat. When water is heated to

240° the steam exerts an additional force of about 15lbs. on every square inch, being equal to the pressure of another atmosphere.

ROBERT. — But I thought you said, father, that water could not be heated above the boiling point; then how can it be made so hot as 240°, which is 28° above boiling?

MR. P. — I said it could not be heated above the boiling point if the steam were allowed to escape; but, by confining the steam, and thus preventing the heat from flying off, water may be made as hot as any other substance, provided the vessel be strong enough.

HARRIET. — Why need it be so very strong?

MR. P. — Because the force of steam at very high temperatures becomes almost irresistible. It is ascertained that at 439° steam exerts a force of 375lbs. on every square inch; and, as the heat is increased, the strength of the steam becomes greater. Mr. Perkins, indeed, is stated to have *heated water red hot*, and to have generated steam that acted with a force of 1500lbs. per square inch. If a vessel the size of a common tea-kettle contained steam of this power, the pressure on its whole surface would exceed 400,000lbs.

FREDERICK. — Can you show us any experiment, father, that will exhibit this elastic power of steam?

MR. P. — Most experiments with high-pressure steam are attended with some danger, and therefore ought to be exhibited with great caution. I think

I can, however, give you some idea of the force of steam by a very simple apparatus. A piece of copper gas-tube, that has one end closed, and a bladder tied to the other, will answer the purpose. (*Mr.* POWELL *produces a piece of gas-tube about a foot in length and a quarter of an inch diameter, brazed at one end, into which he pours a tea-spoonful of water, and then ties a bladder very firmly on to the other end.*) I will now place the end of the tube, where the water is contained, on the fire, in a perpendicular position, that it may become hot. Stand at a distance from it, my children, lest the water should be thrown out and scald you.

HARRIET. — (*Clinging to her father.*) Papa, what will it do? Is it likely to hurt us?

FREDERICK. — Look! look! the bladder is swelling out as if it were blown.

MR. P. — The steam is beginning to form, and is filling the bladder. You see it is now about to burst by the force of the confined steam. (*The bladder bursts with a loud explosion.*)

HARRIET. — Oh dear! what a tremendous noise! I am almost stunned.

MR. P. — The bladder, you perceive, is burst at last, the pressure having become too great for the strength of the bladder to resist it.

FREDERICK. — Is it in this way that accidents happen in steam engines?

MR. P. — Yes, my dear; the bladder in this experiment might represent the boiler of a steam engine, in which the steam was forced up beyond

the power of the boiler to bear it. I very lately saw a boiler that had been blown to the distance of several hundred feet, owing to the bottom of it giving way. It was carried over a building belonging to the works, knocking part of it down in its progress, and scattering death among the work-people within: eight or ten persons were killed, and numbers dreadfully scalded.

ROBERT. — If accidents are so likely to happen with high-pressure steam engines, why are they ever used, when the other kind would do as well?

MR. P. — High-pressure engines possess many advantages which render them preferable in particular circumstances to condensing ones. In the first place, they are cheaper, as the whole apparatus of the condenser is spared. In the next place, it often happens that it is impossible to procure so large a supply of cold water as is required to condense the steam, — in moving engines on rail-roads more especially; and, in the third place, high-pressure steam engines require less fuel.

FREDERICK. — What is the reason of that, father?

MR. P. — I explained to you the other day that water requires to be heated to 212° before the elastic force of steam becomes equal to balance the pressure of the atmosphere; but having attained that point, it only requires 28° of additional heat to double its power; 25° more to treble it, and 18° additional to quadruple it; each succeeding atmosphere of pressure being gained by a lower

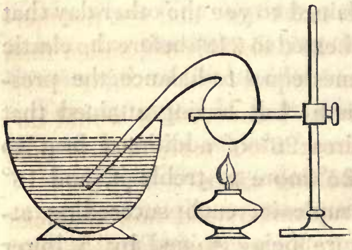
proportion of heat. At a temperature of 367° the force of steam is increased ten times. Now, if the water, before being heated, was at the temperature of 57°, it must require 155° of heat to raise it to the boiling point; the whole of which heat will, after all, only produce steam of force sufficient to balance the weight of the atmosphere.

Frederick. — Yes, I think I see how it is now; 28° degrees of heat added *after* 212° are equal in effect to 155° *before;* for steam formed at 212° will only have one half the strength of the steam from water heated to 240°.

Mr. P. — Yes, Frederick, you are right. Thus you perceive that 155° added to 212° will produce steam possessing ten times the power that the same quantity of heat would produce if employed in raising the water merely to the boiling point.

Robert. — You have told us, father, that steam and vapour contain a great deal of heat; how can this be known?

Mr. P. — It can be proved to be the case by many experiments, but one will be enough for the present. I will put into this retort a quarter of a pint of water, and insert the end of the tube into a basin containing a gallon of water at the



temperature of 50°, and then apply a lamp to the retort till the water boils away. (*Mr.* Powell *arranges the apparatus in the manner described, and exhibited in the annexed wood-cut.*) In the mean time, let us see how much the temperature of one gallon of water at 50° is raised by adding to it a quarter of a pint of boiling water. (*Mr.* Powell *mixes a quarter of a pint of boiling water with a gallon of cold.*) Frederick, observe how much the thermometer rises.

Frederick. — (*Holding the bulb in the water.*) It has risen full nine degrees.

Mr. P. — Very well: now if the steam from the quarter of a pint of water in the retort contain only the same quantity of heat as boiling water, the temperature of the water in which it is condensed will be raised only nine degrees.

Robert. — I should not think it would be so much.

Mr. P. — Frederick, let us know how the thermometer decides the question, for the water is just boiled away.

Frederick. — (*Putting the thermometer into the water.*) The water is quite hot; and see, the thermometer has risen to 118°, which is 68° higher than the water was before.

Mr. P. — That is as I expected it would do; for steam contains about 1000° more of heat than the same weight of boiling water.

Robert. — I do not understand how that can be, for steam cannot be hotter than boiling water.

Mr. P. — An *equal bulk* of steam does not con-

tain nearly so much heat as an equal *bulk* of boiling water; but, you must bear in mind, that one pint of water would fill 1800 pints when converted into steam; and the heat diffused through this large space, when condensed into one pint, is seven times greater than the heat in the same weight of boiling water. Steam or vapour, it is supposed, always contains the same quantity of heat, whether it be formed at a temperature of 60° or 600°.

ROBERT. — What! do you mean, father, that when steam is made three times as hot as boiling water, it does not contain more heat than common steam in a kettle?

MR. P. — I mean that the same *weight* of steam does not; because the more steam is heated the more it is compressed, and, consequently, it weighs heavier; and a smaller quantity of high-pressure steam will therefore be condensed into as much water as a larger quantity of common steam.

ROBERT. — Ay, I think I understand it now: what the steam gains in heat it loses in bulk; is not that it?

MR. P. — Just so. This has been rather a puzzling subject; but I hope I have succeeded in making you understand the general properties of steam. A more particular consideration of the different applications of steam, as a moving power, does not come within the scope of our present consideration; though I may, at a future time, take an opportunity of explaining that subject to you more fully.

CONVERSATION VIII.

CLOUDS, FOGS, AND DEW.

(A thick Fog.)

Frederick. — What a very foggy morning this is! I can scarcely see across the road.

Harriet. — I should like, papa, very much to know what it is that makes these disagreeable fogs.

Mr. P. — If you understood what I told you respecting the nature of steam, I think it will not require much time to explain the nature and cause of fogs. In our conversation upon steam and vapour, we considered only the property of that vapour which is given out by liquids in a boiling state; but fluids, even at their coldest temperatures, are continually, though slowly, being changed into vapour. This slow process is called evaporation.

Robert. — But I thought vapours contained a great quantity of heat; then how can vapour be made in cold weather?

Mr. P. — You cannot, surely, have forgotten

what I so recently explained to you respecting the heat contained in the atmosphere, even at the lowest temperatures. You must remember that, even in the coldest weather we ever experience in this country, the air is quite hot, compared with the temperature near the poles. It is from this source, and from the heat of the earth, therefore, that vapour derives its heat. The process is always going on, though very slowly, compared with the vapour formed at boiling heat.

FREDERICK. — I suppose that evaporation goes on faster in hot than in cold weather.

MR. P. — You are right. In summer the quantity of water evaporated from one acre of land, after heavy rain, is estimated at 1900 gallons in twelve hours. Even when apparently quite dry, the ground is continually parting with vapour to the atmosphere, though not in such large quantities.

HARRIET. — But what becomes of the vapour?

MR. P. — As vapour is lighter than the air near the surface of the earth, it ascends into the colder regions of the upper air, till, being deprived of a portion of its heat, it is partially condensed into water, in the same manner as you observe the steam issuing from the kettle is condensed into a mist. This condensed vapour forms clouds.

ROBERT. — If the clouds consist of water, why do they float so high in the air instead of falling directly to the ground, as water would do?

MR. P. — Each particle of water condensed from the vapour, is so minute as not to be sepa-

rately visible to the naked eye. Its weight is, therefore, not sufficient to counterbalance the resistance of the air to its descent; and when large quantities of these minute particles are collected together, as in clouds, the extended surface they present to the air helps to sustain them. Besides, the whole mass being kept distended by mixture with the air, the weight scarcely exceeds that of the surrounding atmosphere, and must be absolutely lighter than the air near the earth's surface.

Frederick. — Are fogs, then, any thing like clouds?

Mr. P. — Yes, Frederick; they are formed in the same manner. The only difference between them is, that the vapour which forms a fog, is condensed before it can ascend from the earth.

Robert. — But why is vapour sometimes condensed into fog, and sometimes into clonds? why is it not always the same, either all fog or all clouds?

Mr. P. — That entirely depends upon the temperature of the air, as compared with that of the earth, or water, from which the vapour rises. If the surface of the earth be hotter than the surrounding air, the vapour, in this case, obtains the greater portion of its heat from the earth, or water, and, rising into the colder air, it is almost immediately condensed before it can ascend. If, on the contrary, the air be warmer than water, the vapour rises uncondensed. The atmosphere

in the latter case is clear, and in the former foggy.

Robert. — But if the air being colder than the earth makes fogs, the weather ought always to be foggy in a frost, which it is not.

Mr. P. — I am not surprised at your wondering why fogs are not produced by frost. The cause of the atmosphere being generally clear in a hard frost is twofold. In the first place, the water and the moisture on the earth's surface being then frozen, a much less quantity of vapour is formed; and, in the second place, the air condenses the vapour as soon as formed, and it is frozen before it can rise from the earth, and produces what is called a hoar frost.

Harriet. — What is it that makes the grass so wet on summer mornings, when there is no fog?

Mr. P. — It is owing to the comparative coldness of the grass. The earth during the day having become heated by the sun, is hotter than the air after the sun is gone down, and part of the vapour is, therefore, condensed before it can ascend, and forms *dew*. It has been ascertained by the late Dr. Wells, who made a series of experiments with a view to explain the phenomena of dew, that the air close to the earth is several degrees colder during the formation of dew than it is four or five feet from the ground. This difference he supposed to be owing to the radiation of heat from the surface of the earth;

and it is a remarkable fact that on clear nights, when there are no clouds to reflect the heat again to the earth, this difference of temperature is most observable; and on these nights it is that the greatest quantity of dew is deposited. On cloudy and windy nights there is scarcely any dew formed.

FREDERICK. — What is the reason, father, that dew will not fall on highly polished steel?

MR. P. — Dr. Wells found that polished metals, and all substances that radiate heat very imperfectly, are warmer on clear nights than those from whose surfaces heat is radiated more rapidly; and, in consequence of their being warmer, less dew will be formed upon them. The circumstance that dew is deposited in different quantities upon different substances, and that those on which it collects are the best radiators of heat, strongly confirms the radiating theory.

HARRIET. — I should suppose, then, that grass sent out a great deal of heat in this way, for it often seems quite drenched with dew.

MR. P. — Yes, it does, Harriet. Gravel, on the contrary, radiates comparatively very little heat, which is the cause of the walks in the garden being dry when the grass is not fit to walk upon. Wool, cotton, and all fibrous substances, are found to radiate a large quantity of heat, and to become the coldest when exposed on a clear night. But, whatever may be the cause of one substance becoming cooler than another, the effect is the same

as regards the formation of dew; for the vapour will not be condensed, unless the air, or the substances on which dew is deposited, is colder than the vapour.

Frederick. — Then, so long as the air is hotter than the earth, there will be no fogs?

Mr. P. — No, there will not. In spring, before the earth has received much heat from the sun, fogs are not nearly so frequent as in the autumn, at which time the earth is, at night, generally warmer than the air. You have, I dare say, observed the canal, on a frosty September morning, looking as if it were almost boiling. This appearance is owing to the water being much warmer than the air, and the vapour being therefore condensed as it rises from the surface, presents the appearance of hot steaming water.

Harriet. — But, papa, why are fogs so much more common in valleys than on hills?

Mr. P.—Valleys generally contain more moisture than hills, therefore, a larger quantity of vapour is formed there. Besides, the tops of hills are more exposed to the wind, which dissipates the fog.

Harriet. — How does wind clear away fogs?

Mr. P. — It does so in two ways: first, by mechanically blowing the condensed vapour away; secondly, a constantly fresh current of air being brought into contact with the minute particles of water composing the fog, they are dissolved again into vapour.

Frederick.—Is there always vapour in the air?

Mr. P.— Yes, Frederick; in the most brilliant day of summer the air is more charged with vapour than in the foggy days of November; but the heat keeps the moisture in a state of vapour, and it is, therefore, invisible.

Robert. — How can it be known then?

Mr. P. — The existence of vapour may be easily detected. For instance, if on a fine summer's day an empty glass be brought out of a cold cellar into the open air, it will instantly be covered with mist; for the vapour in the air will be condensed by the cold glass, and the moisture will adhere to its sides. In the same manner, when a thaw suddenly succeeds a hard frost, the walls of a house will run down with wet. This phenomenon depends upon the same cause; for in consequence of the thickness of the walls, they cannot change their temperature so quickly as the air, and will remain for some days colder than the atmosphere. By this means the walls condense the invisible vapour, and the moisture adheres to them, and runs down in streams.

Frederick. — Yes, I have noticed the walls of our house do so in a thaw, and I thought it was owing to the house being damp.

Mr. P. — Many a house gets a bad character from the same cause, very undeservedly. The thicker the walls, the longer will the moisture adhere to them, provided the previous frost has been long enough to penetrate the bricks.

Frederick. — I suppose, father, that in the same manner you have explained the cause of fogs, you account for our seeing the breath of people in cold weather.

Mr. P. — You are right, Frederick. The vapour, as it issues from the mouth, becomes condensed by the cold, and is, therefore, rendered visible.

Harriet. — It is very disagreeable to be following people in a frost, and to have all their breath blowing into one's face. That makes me dislike walking in the streets in a frost.

Robert. — Or to come near a horse that is blowing clouds at you through his nostrils — eh, Harriet?

Harriet. — Oh, shocking!

Mr. P. — It is all fancy, Harriet. The same thing takes place in the most beautiful day of summer, but as the vapour is then invisible, you do not think of any annoyance. This, and numberless other annoyances of the same kind, are disagreeable only in idea. You should endeavour, as much as possible, to overcome your aversion to such trifles; if not, you will continually be made uncomfortable, and be disgusted with matters that ought not to give you the slightest uneasiness.

CONVERSATION IX.

RAIN, SNOW, AND HAIL.

Mr. P. — It is raining so very heavily this morning, that I think we cannot do better, my children, than stay at home and endeavour to explain what causes rain to fall.

Robert. — I think there can be no great difficulty in finding out that, however; for every body knows that rain comes from the clouds.

Mr. P. — Then you can perhaps tell us why the clouds sometimes rain, and at other times do not; and why the rain descends in drops of such equal size, instead of coming down in masses.

Robert. — No, I cannot tell that exactly; but I know that it is the clouds that make the rain.

Mr. P. — The rain comes from the clouds, no doubt; but the manner in which rain is made has puzzled older heads than yours, Robert; and we cannot now speak positively as to the cause of rain.

Frederick. — Is it not owing to the condensation of the vapour?

Mr. P. — Yes, it is owing to the condensation

of the vapour; but you must recollect that all clouds consist of condensed vapour, yet all clouds do not rain.

FREDERICK. — Then what is supposed to be the cause, father?

MR. P. — The immediate cause of rain is owing to the partially condensed vapour of the clouds having been rendered more dense than before. In this more condensed state the clouds resemble what are termed *mists*, in which the particles of water are separately visible, though extremely small, and possess sufficient weight to fall to the ground.

ROBERT. — But what can make the clouds more dense at one time than at another?

MR. P. — There are many causes that would account for it. Suppose, for instance, a cloud to be continually receiving fresh supplies of vapour from the earth, which vapour becomes condensed on entering it. The additional vapour, when thus condensed, would unite with the minute particles of water forming the cloud, and, by continual addition, these particles would become minute but visible drops, like a *mist*. Again, if a cold current of air come in contact with vapour at a low elevation in the atmosphere, such vapour will be condensed into larger particles than if it had been condensed higher in the air, where it would have been more expanded; and a cloud formed near to the earth will, therefore, be more dense than when formed after the vapour has risen higher.

FREDERICK. — Then I suppose, father, when

the vapour is most rarefied, the drops of water into which it is condensed are the smallest.

MR. P. — They are, my dear.

ROBERT. — But what makes vapour thinner at one time than at another?

MR. P. — The vapour is more or less rarefied, or, in other words, its elasticity is greater or less, according to the degree of heat at which it is formed. Thus, as I before told you, steam formed at a temperature of 240° has twice the elasticity of steam formed at 212°, the boiling point; and vapour formed on a hot day in summer possesses more elasticity than vapour produced on a cold day in November.

FREDERICK. — Then, does a gallon of the vapour formed in hot weather contain more water than a gallon of vapour formed on a cold day?

MR. P. — Yes, that is the case. The cold vapour is more rarefied than the hot; and, therefore, when condensed, the fog or cloud is not so thick. Besides, the condensation of cold vapour must be carried on more slowly, for the difference in temperature between it and the air is not so great.

FREDERICK. — Does the quick condensation of vapour, then, depend upon the difference in heat between the vapour and the air?

MR. P. — Entirely so. Thus, you perceive that the hot steam from the kettle is instantly condensed as soon as it becomes exposed to the

air; whereas the vapour in the room, formed at the same temperature as the air, remains invisible.

ROBERT. — But how can we be certain that there is any vapour in the room, when we cannot see it?

MR. P. — I can, if you wish it, make the vapour visible.

ROBERT. — Yes, I should like it by all means.

HARRIET. — And so should I, papa.

MR. P. — (*Producing a large empty phial.*) You perceive this phial is apparently quite dry and clean. It is full of the same air as this room. I will cork it up; and now, Robert, look at it. Do you suppose it contains any vapour?

ROBERT. — I think not, for it appears quite dry.

MR. P. — Take it into the cellar for a minute, and see what effect that has upon it.

ROBERT. — (*Returning with the phial after having taken it into the cellar.*) Look, father! the bottle is all dim inside.

MR. P. — That is the vapour you could not see in this warm room, now condensed by the colder temperature of the cellar, and become visible. It is owing to the same cause that the vapour of the breath is condensed on the windows of a carriage. The vapour is invisible in the carriage, because the heat inside maintains it in a state of vapour; but the windows, being cooled by the external air, condense the vapour as soon as it touches them. The frosty crystallisations on the inside of a window may be explained in a similar

way. The vapour in the room is condensed and frozen on coming in contact with the cold glass, and forms there a considerable thickness of ice, whilst in other parts of the room the vapour is not perceptible.

Harriet. — I remember, papa, that when we went on the steam-boat with you, last summer, a shower of small rain came on when the engineer let out the steam, though it was a very fine day: was that owing to the condensation of the steam?

Mr. P. — I am very glad, Harriet, my dear, that you have reminded me of the circumstance, as it is a complete illustration of the formation of rain. The steam, as it issued from the steam-pipe, was condensed immediately into a thick mist by the colder air; and the minute particles of water first formed, having been enlarged by the condensation of more steam upon them, became sufficiently heavy to fall down in drops.

Frederick. — Yes, I remember the shower very well; but the drops were smaller than those in a common shower of rain.

Mr. P. — The smallness of the drops was owing to the small quantity of condensed steam through which they had to fall, compared with the magnitude of clouds. If the mass of steam had been greater, the drops, in descending, would have collected more water round them: two or more drops would have united into one; and they would have become equal to the largest drops of rain.

HARRIET. — Do the drops of rain unite in that way in falling from the clouds?

MR. P. — We must conclude that they do; for it is ascertained that the drops increase in size as they approach the ground. If we suppose the clouds to be of great thickness, we can easily imagine that, as soon as the smallest particles become large enough to descend, they will increase in size by uniting with other small drops in their descent.

FREDERICK. — What effect has the wind in producing rain?

MR. P. — The wind has very opposite effects upon the clouds, depending upon its temperature, its velocity, and the formation of the clouds themselves. A wind warmer than the temperature of a cloud will dissolve it into vapour; and in this way you may often see clouds disappear in the air. If the wind be colder than the cloud, it will condense more vapour around it, and, by compressing the minute particles together, will assist their uniting into drops. If the mass of clouds be sufficiently great to resist the action of the wind, we may suppose that rain will be produced merely by the particles of condensed vapour in the middle of the clouds being compressed together.

FREDERICK. — Then it appears that the wind is the principal cause of rain.

MR. P. — There is reason to believe that it is the chief agent; but there may be other causes which produce the condensation of vapour, that we are at present unacquainted with. We may,

however, take it for granted, that the vapour cannot be condensed until it has parted with the heat that kept it in a state of invisible vapour.

Harriet. — I suppose, then, papa, that snow must be made from vapour that has lost all its heat?

Mr. P. — Not all, Harriet, but sufficient to reduce its temperature to the freezing point. Snow we must suppose to be formed by the freezing of the minute particles of moisture as they are condensed. The hoar frost upon grass and trees is formed in the same manner, and, if closely examined, will be found to consist of a number of small crystals of ice.

Frederick. — What causes the difference between snow and hail?

Mr. P. — Snow is formed, as I have told you, by the freezing of the small particles of moisture before they are united into drops; hail, on the contrary, is first formed into drops, and is frozen as it descends to the ground.

Frederick. — Yes, I understand now how it is; they are both frozen rain; only snow is frozen in the clouds as it is made, and hail is nothing more than rain frozen as it comes down.

Mr. P. — I am glad, Frederick, you have so clearly explained the difference. The subject of this morning's conversation is one of considerable difficulty and intricacy, if pursued in all its bearings; but I trust I have given you a sufficient insight into the causes that may commonly produce rain, to enable you to understand them.

CONVERSATION X.

FIRE.

Harriet. — You have told us, papa, a great deal about heat and cold, but you have not yet said any thing about fire.

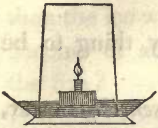
Robert. — Every body knows that the fire in the grate comes from the coals.

Mr. P. — Then every body is mistaken, Robert. The fire does not come from the coals; they are only the means of bringing it into action: the heat comes from the air.

Harriet. — You cannot mean, papa, that the coals do not burn when put on the fire?

Mr. P. — I mean, my dear, that the heat, by which the coals are reduced to cinders and ashes, comes from the air and not from the coals; and that they will not burn unless supplied with air. I will show you that air is necessary for the production of flame, by placing a lighted taper under a glass to exclude the air, when you will perceive that the light will shortly be extinguished. (*Mr.* Powell

fastens a taper to a flat piece of cork, and lets it



float on the surface of water contained in a saucer. After lighting the taper, he covers it with a large glass, as represented in the annexed wood-cut.)

HARRIET. — The taper is going out, papa.

MR. P. — Yes. It is now extinguished.

FREDERICK. — And the water has risen higher in the glass than it was before.

MR. P. — Part of the air has been consumed by the taper, and the water is, therefore, forced higher to supply its place. You may learn from this experiment, that a candle will not burn without air, and that the air is consumed by the burning. The same holds good with regard to the fire; for when the supply of air is stopped, as it can be in some stoves, the fire goes out.

ROBERT. — But how can the air burn, father?

MR. P. — Before I attempt to answer that question, it will be necessary to give you some idea of the composition of the air, and of the property that all bodies, and more especially airs and vapours, possess of containing heat in what is termed a *latent*, or hidden, state.

HARRIET. — What do you mean, papa, by saying that all things can hide heat?

MR. P. — When any substance receives a quantity of heat, without feeling hotter, the heat that it so receives is said to be *latent;* because it is hidden from the senses, and its existence in the

substance is not made apparent by the most sensitive thermometer.

ROBERT. — Is it possible for any thing to be heated without becoming hotter?

MR. P. — Yes; without becoming *sensibly* hotter, as I can readily convince you, if you will fetch me a piece of ice from the tub in the yard, that I saw frozen over this morning; and bring at the same time a pint of the water from under the ice.

ROBERT. — (*Bringing the ice in a basin, and the water.*) Here is the ice and the water, father; if there be any heat in them, it is so well hidden that I cannot find it out.

MR. P. — But the thermometer can, as you know, Robert, from your experience the other day. We do not call the heat in ice latent; for it is very sensibly warm, compared with a mixture of salt and snow. You see the ice and the water are of the same temperature; the thermometer stands in each at 32°. I will weigh a pound of ice, and put it into a saucepan over the fire. When melted, it will be nearly equal in bulk to the cold water, which I will put into another saucepan over the same fire. We shall see presently which is the soonest heated. (*Mr.* POWELL *places the ice and the water on the fire in separate saucepans.*)

HARRIET. — As they both get the same heat from the fire, I suppose one will be as hot as the other. See, the ice is beginning to melt already.

ROBERT. — Yes, it is quite clear that that is getting warm.

Mr. P. — Suppose, when the ice is nearly melted, you should find that the water is no hotter than the ice was at first; what would you think had become of all the heat it is now receiving from the fire?

Robert. — I should think the water could play at hide-and-seek a great deal better than I can; but that cannot be, you know, father.

Mr. P. — Take both saucepans from the fire, for the ice is just melted: put the thermometer into the water dissolved from the ice, and let us know how much heat it has gained.

Robert. — (*Holding the thermometer in the water.*) Why, I declare, the quicksilver has fallen nearly to freezing! and the water really feels as cold as the ice did.

Mr. P. — Now try the other water with the thermometer.

Robert. — This seems to be nearly boiling, and the quicksilver is rising very fast. See, it is at 172°! How very strange this is!

Frederick. — The water has, then, gained 140° of heat, whilst the melted ice does not appear to have gained any; though the same quantity of heat must have entered both.

Mr. P.—The 140° of heat gained by the melted ice are latent in the liquid; that is, it has received 140° of heat, in being converted from a solid into a liquid, without any sensible difference having been produced in its temperature. This quantity of heat seems necessary to keep water in a fluid state, and

must be parted with before it can be again frozen. It can be proved, by other experiments, that ice absorbs, when melting, 140° of heat. For instance, if a pound of water at 172° be mixed with a pound of ice at 32°, the temperature of the mixture would be only 32° instead of 102°, as it would be if equal quantities of water of those temperatures were mixed together: thus, 140° must have become latent, or concealed, in the melted ice. It is owing to this absorption of heat by water that the process of freezing is so very slow; for the water must first part with the heat that preserves it in a liquid state, before it can become solid. Were it not for this provision of Nature, connected with the peculiar deviation which water presents to the expansion of bodies by heat, as already noticed*, our rivers and lakes would speedily be frozen into masses during frost; and, on the first change to milder weather, the snow on the ground would be almost instantly dissolved, and the land would be inundated by the melted torrents.

Frederick. — What other things, besides water, contain heat hidden in this manner?

Mr. P. — All solid bodies, on becoming fluid, either by melting or dissolving, absorb much more heat than the thermometer indicates; and, in the melting of some metals, this quantity exceeds, by four or five times, the quantity absorbed by melting ice. When liquids are converted into airs or va-

* Conversation V., p. 41.

pours, a still greater quantity of heat is rendered latent, than in the change of solids into liquids; the quantity of latent heat generally increasing in proportion to the increase of the bulk of any body by the change. When water is converted into steam (which occupies 1800 times the space of water), 1000° of heat become latent during the increase of bulk; that is, when one pint of water of 212° is changed into 1800 pints of steam, which is also 212°, the 1800 pints of steam will contain 1000° more of heat than the pint of boiling water from which it was made, as I explained to you in our conversation on steam. If the same steam be again condensed into water, its latent heat will be discovered, for it will give out as much heat as a pint of water would do if heated 1000° above boiling heat.

Frederick. — Do you mean, father, that steam, which the thermometer will tell us is only as hot as boiling water, really is 1000° hotter?

Mr. P. — The same *weight* of steam contains 1000° more of heat than the same weight of boiling water; though, as steam is 1800 times lighter than water, the same *bulk* of steam will not contain nearly so much heat as the same bulk of boiling water. As water in melting from ice absorbs 140°, and when in expanding into steam it absorbs 1000° more, steam we may consider as containing 1140° more of latent heat than ice. Steam, when formed at the temperature of boiling water, also contains 180° more of sensible heat than ice at 32°; there-

fore the latent heat and sensible heat together will make the same weight of steam 1310° hotter than the same weight of ice. If we could suddenly condense a pint of steam into a pound of ice, the 1310° of heat would be given out, and would be sufficient to produce the appearance of flame. Now, what would take place in the case of steam, if it could be condensed at once into ice, does actually take place with air during the burning of coals upon the fire.

Frederick. — Air, then, I suppose, contains hidden heat, in the same manner as steam.

Mr. P. — Yes, my dear, it does; though the quantity of latent heat in air has not been accurately ascertained. That it does contain heat, however, may easily be made apparent, by suddenly compressing air in a syringe with tinder placed at the bottom, for the compression of the air will cause it to give out sufficient heat to set fire to the tinder.

Frederick. — Does air become solid, then, father, by burning in the fire?

Mr. P. — A great part of the air that is consumed is converted into water, which is 600 times smaller in bulk than air; and this condensation of air into water produces flame in fires. *

* Lavoisier's theory of combustion has been adopted to explain the cause of fire, because, whatever difficulties may attend the general application of this theory, it appears to be admitted that the heat and light evolved in common combustion are principally produced by the liberation of latent heat.

HARRIET. — What, papa! do you mean that it is water that makes the fire burn? That is the strangest thing you have told us yet; for water, we all know, puts out fire.

MR. P. — Yes, Harriet, it may seem very extraordinary, but it is the fact; and though water extinguishes fire, no fire blazes without producing water.

ROBERT. — Well, if fire and water are the same, I shall not believe my senses any more.

MR. P. — Remember, Robert, they have failed you already in your attempts to distinguish hot from cold.

FREDERICK. — But how is it, father, that air can be changed into water? and in the fire too, where we always suppose there cannot possibly be any?

MR. P. — To enable you to understand this interesting subject, it will be necessary to enter into an explanation of the nature and composition of the air of the atmosphere; and as that will occupy some time, I will postpone the consideration of it until to-morrow.

CONVERSATION XI.

FIRE *(continued)*.

FREDERICK. — I am quite anxious, father, to know what the air can be made of, that it should be changed into water by the fire.

MR. P. — The air we breathe is composed of a mixture of two airs, or gases, called *oxygen* and *nitrogen*; in the proportion of one fifth part of oxygen to four fifths of nitrogen. It is the oxygen gas in the air that causes combustibles to burn in it. If that gas be taken away, the most combustible body will not burn in the remaining nitrogen; and if any lighted substance be put into pure oxygen gas, it will burn with greatly increased brilliancy. I have prepared a jar of that gas, to enable you to see this effect. When I let this small lighted taper down into the jar, you will perceive how much more brilliant it will become. (*Mr.* POWELL *ties the taper to a piece of wire, and when lighted he introduces it into the jar of oxygen gas.*)

HARRIET. — How very beautifully it burns! It is almost too bright to look at.

Frederick. — What is that mist I see round the jar, father, now that the taper is burnt out?

Mr. P. — That is the water formed by the burning of the taper; and in that water you see the oxygen gas condensed into a liquid.

Robert. — Is it like common water?

Mr. P. — Yes, it is water in its purest form. All water is composed of two substances; which we know, when separate, only in the form of gas: these substances are *oxygen* and *hydrogen*. Hydrogen gas is sixteen times lighter than atmospheric air; yet, though so very light, it forms a great part of most combustibles, with which it is united in a solid form. Hydrogen and oxygen gases have a very strong attraction for each other, so that when heated to 800° they instantly unite, and condense from the expanded form of gas into water, which is the product of their union. Water, therefore, is a mixture of hydrogen and oxygen. The proportions in which they unite to form water are, eight parts by *weight* of oxygen to one of hydrogen; but as hydrogen gas is so much lighter than oxygen gas, the proportions, when measured by the *bulk* of the two gases, are eight measures of hydrogen to two measures of oxygen.

Robert. — But how can it be known that water is a mixture of these two gases?

Mr. P. — By burning a mixture of oxygen and hydrogen gases in a closed vessel, the product is found to be water; and the quantity of water formed, is just equal to the weight of the gases burned.

Again, water may be separated into its two gases by passing steam through a red-hot tube containing iron wire; for in this case the oxygen in the steam, having a greater attraction for the hot iron than it has for the hydrogen, unites with the wire, and leaves the hydrogen, which passes along the tube, and may be collected separately. The oxygen will become solid in the iron; and when the wire is taken out of the tube, it will be found to be covered with rust, and to be heavier than before, in consequence of its combination with the oxygen that previously existed in the steam.

Frederick. — Then, is rust solid oxygen, father?

Mr. P.—It is oxygen united with iron; and the rusting of iron is owing to its great attraction for oxygen.

Robert. —But if the burning of the fire be owing to the condensing of oxygen from the air into water, by mixing with hydrogen, where does the hydrogen come from for it to mix with?

Mr. P. — From the coals, Robert, which contain a great quantity of hydrogen in a solid state, in the same way as rusted iron contains oxygen. The hydrogen in coals may be driven from them in the state of gas, by merely heating them in closed vessels, to prevent the hydrogen from uniting with the oxygen of the air. It is in this manner that the gas is produced with which the streets and shops are so brilliantly lighted.

Robert. — But it very often happens, that the

fire does not blaze at all; and it seems to be hotter when the coals are of a bright red heat than when they are blazing.

Mr. P.—The red heat in the coals is produced by the union of the oxygen in the air with another substance in coals, that constitutes the principal part of their weight; this substance is charcoal, called by chemists *carbon.* Oxygen has, indeed, a greater attraction for carbon than it has for hydrogen; but their rapid union, so as to produce combustion, does not take place until exposed to a higher temperature than hydrogen. Now, when coals are heated in a fire-grate, the heat is sufficient to produce this rapid union between the carbon, or coke, in the coals, and the oxygen of the air; and the red heat we see is occasioned by the oxygen uniting with the coke. The combustion that thus takes place is much slower than when oxygen unites with hydrogen, because the carbon, or coke, being solid, the union proceeds only on its surfaces; whereas, in the union of the two gases, it takes place through the whole mass. When the combination of the oxygen and carbon is quickened by a blast of air from the bellows, the heat is greatly increased; and in a blacksmith's forge it is so intense, that the light given out is more brilliant than that of common flame.

Frederick.—Does the burning of charcoal and oxygen form water, as well as the burning of oxygen and hydrogen?

Mr. P. — No, my dear; the result of their union is a transparent gas, containing the carbon in solution, and called *carbonic acid gas.* This gas is sometimes called "fixed air;" and it is the same as that which is compressed into soda water, and which rises in bubbles in bottled porter, and many other fermented liquors. When a piece of charcoal is burned in oxygen gas, it entirely disappears, and is dissolved in the gas. The oxygen gas is then changed into carbonic acid gas, which is perfectly transparent, though it contains the charcoal in solution; and the weight of this gas is exactly equal to the weight of the oxygen and charcoal together.

Frederick. — Is the flame of a candle produced by the union of oxygen and hydrogen, or by oxygen and charcoal?

Mr. P. — It is by both; for tallow and oil are composed of carbon and hydrogen. When the wick of a candle is lighted, the heat produced is sufficient to enable the hydrogen of the tallow to combine with the oxygen of the air, and form water. The carbon that was previously united with the portion of hydrogen consumed, is thus set at liberty; and, if the heat be sufficiently great, it also unites with a fresh portion of oxygen, and forms carbonic acid gas. But, as the carbon and oxygen require a greater degree of heat to enable them to combine than the hydrogen and oxygen, part of the carbon is frequently not burned, and rises in the form of smoke.

FREDERICK. — Then the light from the flame of a candle is produced by two burnings of two separate quantities of oxygen; first, by its uniting with the hydrogen in the tallow, and then with the carbon.

MR. P. — Yes. The hydrogen, as it requires less heat to combine with the oxygen, is the first to inflame, and gives that blue light you may perceive on the first lighting of a candle; then, as the carbon separates, and acquires sufficient heat, by the increase of the flame, to unite with the oxygen, it also burns. But, as the hydrogen is the first to take the oxygen from the air, it frequently happens that the supply of air to the middle of the flame is not sufficient to afford oxygen enough to burn all the carbon liberated from the tallow or oil. This is the cause of common lamps so frequently smoking, and the defect is remedied in the Argand lamps by allowing a current of air to pass through the middle of the flame. By this method a sufficient supply of oxygen is obtained, and the lamp burns with greater brilliancy in proportion to the quantity of air consumed.

HARRIET. — I should never have supposed that so many changes and mixtures were taking place as the candle flames away, and the coals are burning to ashes.

MR. P. — You must not suppose, Harriet, that the coals or the candle are absolutely consumed; there is nothing destroyed by being burnt.

Harriet. — Not destroyed, papa! Why, what becomes of the candle and the coals?

Robert. — I suppose they are hidden, Harriet; and that, if you only knew how to look for them, you would see candles and coals piled up latent in the air, as heat is — ha, ha, ha!

Mr. P. — Very good, Robert, and more true than you seem to imagine. When any combustible substance is burned, the elements of which it is composed are merely undergoing a change of form, and are no more *destroyed* than sugar is destroyed by being dissolved in a cup of tea.

Robert. — Then what becomes of the tallow in a burning candle, father?

Mr. P. — The hydrogen of the tallow, I have told you, forms water by its union with oxygen, whilst part of the carbon rises in smoke, and part of it also unites with oxygen, and forms a new kind of gas. When any substance is burned, the weight of the product, after burning, is *greater*, instead of being *less*, than it was before; and the increase of weight is equal to the quantity of oxygen united with it. Thus, if we were to collect the product of a burned candle, we should find that the water, and the carbonic acid gas, and the smoke, would weigh more than the original weight of the candle; and if it were burned in pure oxygen gas, we should find that the weight it had gained, was just equal to the weight of the oxygen gas consumed. Though we cannot reproduce the candle in the same shape as before, we can collect

all the materials of which it was made, mixed with another ingredient (oxygen) that increases the weight of the product.

HARRIET. — Well, if fire cannot destroy things, I do not know what can.

MR. P. — Nor do I, Harriet. All substances are indestructible; and, during the apparent decomposition of bodies, their component elements are merely undergoing new changes, to re-appear in another and more beautiful form. The changes that are continually going on in the works of Nature afford some of the most interesting subjects of contemplation that can occupy the mind of man. In the vegetable world, for instance, we witness the progress of decay with each succeeding winter; and, to a spectator not favoured with the light which science affords, the leaves rotting upon the ground may appear as symbols of rapid and total destruction: but, to a more penetrating eye, the decomposition of those objects which during the summer months clothed the scene in beauty, is regarded as a necessary process for resolving the vegetable matter into its original elements, to be again employed in renewing the foliage on the return of spring.

CONVERSATION XII.

THE BAROMETER.

Mr. P. — What a beautiful day this is! and I am glad to see the barometer promises a continuance of such weather.

Harriet. — How is it, papa, that you can tell, by looking at the barometer, what kind of weather it is likely to be?

Mr. P. — The mercury in the tube rises or falls as the air becomes lighter or heavier, and we can generally tell by the weight of the atmosphere what kind of weather to expect.

Frederick. — Then does the weight of the atmosphere vary, father? I thought it was about equal to a pressure of fifteen pounds on every square inch.

Mr. P. — That is about its usual pressure, but its actual weight is continually varying; as we know by the height of the column of mercury it will sustain in the barometer. The extent of this variation in England is as much as three inches; that is, the atmosphere will at one time be capable of supporting a column of mercury thirty-one

inches high, whilst at other times it will not support more than a column of twenty-eight inches. The weight of a column of mercury thirty inches high, and one inch square, is fifteen pounds; therefore each inch weighs half a pound, and it requires half a pound of pressure on every square inch to raise the mercury one inch in the tube. Thus, you perceive that the pressure of the atmosphere varies in England as much as a pound and a half on every square inch, which is one tenth part of its whole weight.

Frederick. — Does the real weight of the air alter with its change of pressure on the earth?

Mr. P. — That is generally the case; for the air being an elastic body, it expands, and, consequently, becomes lighter, when any of the pressure is removed. Whenever part of the pressure from the air above is taken away, the air expands in proportion to the diminished pressure; therefore, by knowing the change of pressure, you can *generally* ascertain its change of weight. Under certain circumstances, however, the pressure may continue the same, though the air becomes lighter, as I shall soon explain; but before we proceed further, I will make you acquainted with the construction of the barometer.

Harriet. — Shall you take yours to pieces, father?

Mr. P. — No, Harriet; I shall be able to show you the nature of it as well with this barometer tube. It is thirty-six inches long; and when I fill it with mercury, and invert it in a cup full of the

same fluid, part of the mercury will run out, leaving a vacuum at the top; but a column, equal to the pressure of the atmosphere, will remain suspended in the tube.

HARRIET. — Why does it not all run out?

MR. P. — Because the pressure of the atmosphere on the outside prevents it. I will put the cup of mercury, with the tube, under the receiver of the air pump, and by exhausting the air the mercury will descend. (*Mr.* POWELL *adjusts the tube into the top of the receiver, and begins to exhaust the air.*) Observe, the mercury falls as I remove the pressure.

HARRIET. — Yes, I see it is now within a few inches of the quicksilver in the cup.

MR. P. — When I admit the air again, the pressure will force the mercury up the tube as high as before. Look! it is rising rapidly.

HARRIET. — Yes, it is as high as ever.

MR. P. — It remains suspended about thirty inches from the surface of the mercury in the cup; therefore the weight of a column of mercury of that height is equal to the weight of a column of air, of the same size, reaching to the top of the atmosphere.

FREDERICK. — Then, I suppose, if a tube were filled with a liquid lighter than quicksilver, it would require a much higher column to balance the weight of the atmosphere.

MR. P. — You are right, Frederick. A column of water thirty-four feet in height would be required to balance the pressure; and of spirits it would require a still higher column.

Frederick. — If the pressure of the atmosphere depend upon the height and weight of the column of air above us, I should suppose that at the top of high hills the pressure must be less, as the column of air above must there be shorter.

Mr. P. — That is exactly the case; and the mercury in the barometer falls when the instrument is elevated. Indeed, a very sensitive barometer would indicate a difference in the weight of the air on the ground and on the chimney-piece. The barometer is now commonly used to measure the heights of mountains.

Robert. — How much does the quicksilver fall as the barometer ascends?

Mr. P. — It is ascertained that the weight of a column of air eighty-seven feet high (when the atmosphere supports thirty inches of mercury) is equal to the weight of a column of mercury one-tenth of an inch high; therefore, when the barometer is raised eighty-seven feet in the air, the mercury falls one-tenth of an inch.

Robert. — Then would it fall one-tenth of an inch for every eighty-seven feet of height?

Mr. P. — No, my dear; for as we ascend higher, the air becomes more rarefied, in consequence of the pressure upon it being diminished; therefore a second column of eighty-seven feet will not weigh so much as the first, and the barometer must be elevated more than eighty-seven feet to cause the mercury to fall one-tenth of an inch. At the height of seven hundred feet, for instance, the weight of

a column of air eighty-nine feet high is only equal to the weight of a column of eighty-seven feet near the ground.

Harriet. — Why is a thermometer fixed to a barometer frame?

Mr. P. — The weight of the mercury in the barometer tube varies according to the change of temperature, as I showed you in the experiment with heated mercury in a former conversation.* When the mercury is made lighter by heat, it rises higher in the tube, even when no change has taken place in the pressure of the air. In accurate observations, therefore, it is necessary to know the degree of expansion, that allowance may be made for it, in calculating the weight and pressure of the atmosphere.

Harriet. — What makes the air heavier at one time than at another?

Mr. P. — That is a very puzzling question, Harriet, and one on which philosophers are not agreed.

Robert. — I should think there cannot be much difficulty in the matter; for as heat expands air, and makes it lighter, the change must depend upon hot and cold weather.

Mr. P. — There is much more difficulty, Robert, than you conceive. Most persons who have not attended to the subject would, I dare say, think with you, that when the air is lightest the pressure

* Conversation V. on Expansion by Heat, p. 35.

is the least, but we find that in the hottest weather the barometer is often the highest.

Robert. — But if the pressure of the air be owing to its weight, the pressure must be least when the air is lightest.

Harriet. — Yes, papa, I think Robert must be right there.

Mr. P. — I do not wonder at your thinking so; and those persons who are more pleased with sounds than with philosophical researches would pronounce Robert's logic to be unanswerable, and without paying more attention to the matter, be content to remain in ignorance all their lives.

Frederick. — I confess I thought what Robert said was very true; for if a column of air reaching from the ground to the top of the atmosphere weighs, when the air is heavy, only fifteen pounds, how can it weigh as much when the air is light?

Mr. P. — If we take for granted, as you seem to do, that the whole atmosphere is equally affected by change of temperature, then the expansion of the air by heat would raise the atmosphere higher; and in this way it might make up, by its increased height, for the loss of specific gravity.

Frederick. — I had forgotten that the atmosphere might rise higher at one time than another.

Robert. — But is the atmosphere raised higher in hot weather, father?

Mr. P. — We may, perhaps, safely conclude that in summer time, when the air in this part of the globe is more heated than in winter, our

atmosphere is actually higher; but partial changes of temperature near the surface of the earth, of mere local extent, can have but a slight effect in elevating the atmosphere.

Robert. — But if the pressure of the atmosphere be not changed by the air being made lighter, I cannot think what else can produce any change in its weight.

Mr. P. — The principal cause of the variation of the pressure I believe to be the wind.

Robert. — How can the wind alter the pressure of the atmosphere?

Mr. P. — The horizontal motion of the air may diminish its pressure. Air is subject to the same laws that regulate other liquids in motion, and we find that a quick horizontal motion communicated to fluids, not only diminishes their perpendicular pressure, but absolutely suspends it altogether. Thus we see water spouting out horizontally to a considerable distance from a hole at the bottom of a water-tub; the gravitation, or weight of the water, being suspended by the force with which it is impelled in a horizontal direction. In the same manner we may suppose the weight of the atmosphere becomes affected by currents of air, which when in motion have the whole or part of their weight suspended: and the pressure is lessened according to the depth of the current and the rapidity of its motion.

Robert. — The effect of motion on the weight of the air is, then, the same as upon solid bodies;

for I know that ice will often bear a person, when skating quickly over it, that would break if he were to stand still.

Mr. P. — Yes, that is a good illustration of the effect of horizontal motion in diminishing perpendicular pressure. The throwing of stones, the firing of cannon balls, &c., are also instances of the same power exerted on solid bodies, and suspending, for a time, all their weight. I can show you a very curious experiment that will illustrate the effect of horizontal motion upon air most remarkably.

Harriet. — Pray do, papa.

Mr. P. — You perceive that in the side of this tube, open at both ends, there is a small hole. Now I will place this hole close to the flame of the candle whilst I blow through the tube, and you will observe that the flame, instead of being blown away, as you might suppose, will be drawn in towards the hole. (*Mr.* Powell *blows through the tube, and the flame is evidently attracted to the hole, at which the children express much surprise.*)

Robert. — Well, I cannot think how that can be, if you blew, father, and did not draw in your breath.

Mr. P. — You may try the experiment yourself, Robert. (Robert *blows through the tube, in the manner represented in the annexed woodcut with the same result; and then*

FREDERICK *and* HARRIET *also try the experiment with similar success.*) You seem to be quite astonished; but the wonder is easily explained on the principle of horizontal motion removing atmospherical pressure. Whilst the air inside the tube was at rest, it exerted a pressure against the interior, equal to the pressure of the atmosphere on the outside; consequently, both forces being equal, they balanced each other. But when you blow through the tube, the pressure of the air against the inside is diminished by the motion, and the pressure of the atmosphere on the outside forces the air into the hole, and carries with it the flame of the candle.

ROBERT. — Then the harder you blow the greater will be the draught of air into the hole?

MR. P. — Yes, if the tube be enlarged towards the end, to admit a more free passage of the air; but if the air be obstructed in its progress, it will be compressed, and force itself through the hole.

HARRIET. — It is a very curious experiment.

MR. P. — The same effect may be produced by blowing between two slips of paper, about six inches long, and three inches wide. If you place the slips of paper over one another and hold two of the corners together, so that when applied to the mouth you can blow between them at their narrowest edge, the effect of the blast of air will be to bring the two slips of paper closer than before, instead of to separate them farther, as you might suppose it would. These experiments afford

a very good illustration of the effect of wind in lessening the pressure of the atmosphere.

Robert. — Does the barometer fall during wind?

Mr. P.—Yes, my dear; the mercury never falls so low nor so suddenly, as during a high wind.

Robert. — But if the motion of the air take off the pressure, it ought, during a very high wind, to remove it altogether.

Mr. P. — And so, perhaps, it would if the whole atmosphere were in rapid motion. The winds near the earth, however, do not extend very high in the atmosphere, and a much greater proportion of the air has its perpendicular pressure undisturbed.

Frederick. — But does not the barometer often fall when there is no wind?

Mr. P. — It often varies when the wind is scarcely perceptible to us; but there are continual currents in the upper air which we cannot perceive; and it is to these that the changes in the pressure are to be generally attributed.

Frederick. — Does the barometer vary as much in all parts of the world as it does in England?

Mr. P. — Not by any means. Its greatest variations take place in the temperate zone. In the tropics, indeed, where the wind generally blows in one direction for months together, the barometer seldom varies, excepting during storms. This fact confirms the opinion that these changes

are owing to the winds. In our own variable climate, the wind is not often settled for three days following; but when it does continue to blow from one quarter, we generally find the barometer either to rise or fall during the whole time. — The changes that are continually taking place in the pressure of the atmosphere are severely felt by persons in delicate health, and it is only surprising that we do not feel them more. To raise the mercury one inch, the pressure of the atmosphere must have increased half a pound on every square inch of surface of our bodies; it must, therefore, increase the whole external pressure, on an average, about eight hundred pounds. A change to this extent often occurs in a few hours, yet most of us are not aware of any change in the pressure on our bodies. The whole pressure of the atmosphere, on the body of a moderate sized man, may be estimated at twenty-five thousand pounds.

FREDERICK. — Can you explain to us, father, how it is that we are able to bear so great a pressure without feeling it?

MR. P. — The elasticity of the blood, and of the air contained in the body, counteracts the effects of the external pressure. When the weight of the atmosphere is increased, the change is generally communicated, through the lungs, to all the animal fluids so gradually that the variation is not perceived; but when the change is so sudden as not to allow time for the densities of the fluids

and air vessels to accord with the altered pressure, considerable pain is experienced. In diving bells, for instance, as the weight of water above compresses the air within, if the bell be lowered quickly a most painful sensation is produced, particularly in the eyes and ears, owing to the increased pressure.

THOMAS. — You have not told us yet, father, how it is that the barometer can tell what kind of weather we are to have.

MR. P. — Not long after the invention of the barometer, it was discovered, that when the mercury was high the weather was generally fine; and, on the contrary, that the fall of the mercury was followed by rain. It was, therefore, called a *weather glass*. The cause of these phenomena attending the rise and fall of the barometer is not yet very accurately ascertained. The commonly received opinion is, that as the air becomes light and unable to sustain the clouds, they descend in rain.

FREDERICK. — Does rain always follow after the fall of the mercury?

MR. P. — Very frequently not; and sometimes, indeed, we have fine weather when the barometer is very low; and, on the contrary, we have rain when the mercury is high in the glass. The barometer will often be rising gradually, day after day, though it is raining all the time; but when the barometer has risen or fallen for several successive days, such rise or fall is generally fol-

lowed by fine or stormy weather. We can, in general, judge with more correctness of the weather by knowing whether the mercury be rising or falling, at the time, than by the height at which it actually stands. Thus, if the mercury be at 30 inches, which is marked " fair " on the scale, yet if we find, on gently shaking the barometer (to disengage the mercury from the glass), that it is falling lower, we may expect rain. — Our conversation has been longer than usual this morning, but the pressure of the atmosphere varies so materially in this country, and the causes of its variation are, generally, so little understood, that I thought it advisable to enter more into the subject. It is one attended with considerable difficulty, and though, to me, the explanation I have given of the changes in atmospheric pressure seems sufficient to account for all the phenomena, there are many persons who think it necessary to adduce various other causes to explain them. The vapour in the atmosphere is supposed by some to be chiefly instrumental in producing the changes in the barometer, but it can be readily shown, that the mercury rises and falls quite independently of the quantity of vapour in the air. Upward and downward currents of wind are also supposed to have great influence on the weight of the atmosphere; but the horizontal motion of the air appears to me to be sufficient to account for all the changes in its pressure.

CONVERSATION XIII.

WINDS.

Mr. P. — As I yesterday attributed all changes in the pressure of the atmosphere to the motion of the air, we will now proceed to consider the causes of that motion. Can any of you form an idea upon the subject?

Frederick. — The winds may be caused, perhaps, by the heat of the sun expanding the air.

Mr. P. — You are very near the truth, Frederick. When a portion of the atmosphere near the earth is expanded by heat, it becomes lighter than the air above, and ascends till it arrives at a stratum of air as light as itself. The surrounding heavier air rushes to supply the place of that which is ascending; this air, in its turn, also becomes heated, and ascends; and in this manner a current of air is produced, rushing towards the heated space.

Frederick. — Does not the same thing happen in a room with a fire, for we always find a draught of air from the door and windows towards the fire-place?

Mr. P. — That is a very correct illustration, Frederick. The air, as it is heated, rises up the chimney, and the colder and heavier air rushes into the room to supply its place. Were the earth and sun stationary, the wind would be always blowing towards the same point; but the diurnal revolution of the earth, and its motion round the sun, cause a constant change in the part most heated by the sun's rays.

Robert. — But as the sun rises in the east and sets in the west, the wind ought always to follow in the same direction.

Mr. P. — And so, in all probability, it would, if our globe were covered with water, instead of being divided into water and land, mountains and valleys.

Robert. — How can the hills, and valleys, and seas, alter the winds?

Mr. P. — In a variety of ways, my dear. The sun's rays, when striking upon the ocean, penetrate deep into the body of the water, heating the whole mass; therefore a comparatively small portion of heat is reflected into the air. The greater evaporation from water, too, cools its surface, and both causes contribute to prevent the air over water from being nearly so much heated as the air on the surface of dry land. The hills and mountains act as so many screens to check and alter the course of the wind. They also cool the air as it passes over their snow-capped summits; and in consequence of the elevation of the land, the

temperature of many places, even under a vertical sun, is much colder than any we experience in this country. Every circumstance that tends to change the temperature of the air produces a variation in the winds: they must even be affected by the passing clouds, which screen the direct heat of the sun from the earth, and thereby check the expansion of the air.

Frederick. — Do the winds, then, never blow regularly?

Mr. P. — Yes, my dear, in those parts of the world where the causes I have mentioned as producing changes in the wind do not operate with sufficient force to counteract the power of the sun. On the Atlantic and Pacific oceans the wind blows constantly in the direction of the sun's course, throughout nearly all the space included between the 30th degrees of north and south latitude. These winds are called the *trade winds*, from their great importance to navigators: their direction is nearly east at their farthest limits from the equator, but they gradually incline towards the equator as they approach it.

Frederick. — Would not the trade winds blow as regularly if that part of the world were dry land instead of being covered with water?

Mr. P. — No; their regularity is owing to the absence on the ocean of the causes which produce changes in the wind on land; the water of the ocean being there of nearly one equal temperature, and presenting no elevations to check or alter the

course of the wind. Even the trade winds become changeable near land, and in the Indian Ocean their regular course is so much affected by the changeable temperature of the land on the Continent of Asia, that, instead of blowing throughout the year in one direction, the winds blow for six months from the north-east, and for six months from the south-west. This change takes place as the position of the sun is removed from the northern to the southern side of the equator: these winds are called *monsoons*.

Robert. — How can the land on the continent of Asia produce this regular change?

Mr. P. — During our summer months, when the sun is north of the equator, the land on the north of the Indian Ocean becomes intensely hot, and the air, being rarefied, rises, and causes a current of wind to set in from the sea towards the land, to supply the place of the ascending air. When the sun is south of the equator, the land becomes cooler than the Indian Ocean, and the current of air is consequently changed. The different effects of water and land in expanding the air, and varying the course of the wind, are strikingly exhibited in the *land breezes* and *sea breezes* of tropical climates. The sea breeze sets in every morning about ten o'clock, and blows with delightful freshness towards the shore; and in the evening the land breeze begins to blow towards the sea, and continues in that direction throughout the night. The sea breeze is pro-

duced by the greater rarefaction of the air over land during the day, which causes the cooler air from the sea to rush towards the shore. The land breeze, on the contrary, is owing to the more rapid cooling of the land during the night; for the air as it cools being condensed, a partial vacuum is formed, which is supplied from the upper atmosphere; and the land air being then heavier than the air over the water, rushes towards the ocean as the lighter air ascends.

Harriet. — I have been thinking, father, that as the world is always turning round, its motion must move the air, and cause a wind.

Mr. P. — The air moves round with the earth; therefore, as we are all moving together, we are not sensible of its motion. If the air did not move with the earth, we should be forced against it with so much velocity as to produce a wind ten times stronger than that of a hurricane; nothing could withstand the force of its resistance; and all objects exposed to the action of such a wind would be either levelled with the ground, or carried round the world.

Frederick. — Does not the motion of the earth, then, give any motion to the air that we can perceive?

Mr. P. — It is supposed, by many philosophers, that the rotary motion of the earth causes the trade winds to blow from the east instead of from the north, in consequence of the earth at the

equator moving much more rapidly than it does farther north or south.

Frederick. — How is that, father?

Mr. P. — If you look at this globe you will perceive that the different circles drawn round it, to mark the latitudes, diminish in size as they approach the poles. Now these circles represent the comparative spaces through which any point upon them moves at one revolution. This circle, near which St. Petersburgh is placed, is only one half the size of that round the middle of the globe; yet, as both move round in the same time, any point on the central circle must move twice as fast to complete its journey as St. Petersburgh, which is in the sixtieth degree of latitude.

Frederick. — Yes, I see that, as I turn the globe round, the parts near the equator move so quickly, that I cannot distinguish them; whilst the places near the pole are moving so slowly that I can read their names. How is this difference in the motion supposed to alter the direction of the trade winds?

Mr. P. — Those who ascribe the effect to this cause take it for granted that the wind from northern latitudes in moving towards the tropics must have a motion directly south. Now, as the air at the equator is moving round with the world at the rate of about 1000 miles an hour, whilst the air at St. Petersburgh is moving with only half that velocity, if a portion of the air from St. Petersburgh could be conveyed in one hour to the equator,

when it arrived there it would be 500 miles west of the longitude of that capital, because the land at the equator would have moved through a space of 1000 miles in the hour, whilst the rotary motion of the St Petersburgh air would be only 500 miles in the same time. If the same air were to be twenty-four hours in completing its journey to the equator (still retaining its comparatively slow rotary motion of 500 miles an hour, whilst the equatorial land was moving at the rate of 1000), by the time of its arrival there, the air at the equator would have completed one whole revolution, whilst the air from the north would have completed but one half, and would arrive at the equator on the opposite side of the globe to that from whence it commenced its journey. All objects turning round with the globe, on coming in contact with air not moving so fast as themselves, would strike against the slow-moving air, and the sensation produced would be the same as if the wind were blowing against them. Thus, such a wind as we have been supposing, though really not travelling so fast as other objects by 500 miles an hour, would appear to be blowing against them with that degree of velocity; and as the motion of the earth is from west to east, the wind would seem to be blowing from east to west.

Robert. — Just in the same way, I suppose, as the wind always seems to me to be blowing in my face when I am running.

Mr. P. — Yes; just so.

Robert. — But if the world really does slip from under the air, winds blowing south must lose ground, and appear to be blowing east; and that would really account for the east trade winds.

Mr. P. — Yes, Robert, *if* the world do slip from under the air; but there appears to be no sufficient reason to imagine that it does so to an appreciable extent. When any portion of the air in the northern hemisphere is moving south, towards the tropic of Cancer, this motion, we may presume, is caused by the rarefaction of the air drawing, or impelling, the wind towards some particular point; and as this point revolves with the earth, we must suppose that the attraction would be sufficiently powerful to draw towards that point the air which it has once set in motion, so long as the attractive power continued in force. For instance, suppose a rarefaction of the air over the great sandy desert of Africa were to attract the air over London, and cause it to move directly southward at the rate of twenty-five miles an hour, the force of this attraction would prevent the air from shifting westward, and would continue to draw it towards the same point so long as the cause was in operation, however much faster that point might be moving round than the air it attracts. Wind travelling from London to the desert of Africa, at the rate of twenty-five miles an hour, would have an average tendency westward of about four miles at the end of each hour; but the attraction southward, and the friction from

the surface of the earth and from the air, in the course of twenty-five miles, would be sufficient to communicate to the air the extra rotary motion of the land nearer the equator, as the wind proceeded southward.*

FREDERICK. — Is wind produced by any other cause besides heat?

MR. P. — As the attractions of the sun and moon are sufficiently powerful to draw the water of the ocean from its level, and to cause the tides, we may presume that they would have great power in attracting the more volatile air. If this be the case, the atmosphere must be subject to tides as well as the ocean. Though these ebbs and flows of the air may not be perceptible near the earth, any more than the ebbs and flows of the ocean

* The oblique motion of water poured upon a globe revolving round a perpendicular axis has been adduced as an illustration of the manner in which the air in moving southwards receives a westerly direction; but this illustration is far from being a correct representation of the motion of the air; for the point of attraction, drawing the water to the ground, is stationary; whereas, in the case of the winds, the attracting power revolves with the globe. — It has been considered advisable to give the foregoing account of Hadley's rotary theory of the trade winds, and to state some of the objections that may be urged against it, though the subject does not altogether come within the province of the present work, because this theory has been stated, in some elementary works in deservedly great repute, as if it were indisputably true, and the juvenile mind might thus be led to consider a very questionable, if not altogether erroneous, theory as a fundamental truth.

are at the bottom of the sea, yet they may exert considerable influence in altering, checking, and accelerating the upper currents of air.*

Robert. — You did not mention the moon, father, yesterday, in speaking of the pressure of the atmosphere; yet it must have great power in altering the pressure, if it can draw the air after it.

Mr. P. — No, I did not, because I conceive the chief influence the moon can possess, in varying the pressure of the atmosphere, must depend upon its producing upper currents of air, and the cause of these currents I deferred speaking of until we considered the causes of the winds.

Robert. — But if the moon raise the atmosphere higher without lessening the weight of the air, surely the pressure must be greater in that part?

Mr. P. — No, Robert; the attraction of the moon would be fully adequate to keep off the pressure of the extra quantity of air it accumulated; therefore, though the quantity of air would be heavier if the moon's attraction were removed,

* Among the many theories advanced to account for the phenomena of the winds, one of the most novel is that lately published in an American scientific journal, in which all air in motion is supposed to be revolving round a central point. This revolving motion would account for the frequently observed partial actions of storms, but it would scarcely be reconcileable with the general motion of the winds, nor does the proposer of the theory show very clearly how the air could receive this gyratory motion.

yet as that attraction would continue as long as the atmosphere was raised by it, the pressure would not be increased.

FREDERICK. — How fast does the wind usually travel?

MR. P. — In a very high wind the air travels at the rate of one hundred miles an hour. Aëronauts have been carried in balloons the distance of seventy miles within the hour, and yet they could not have travelled as fast as the wind itself.

FREDERICK. — The power of the wind must be very great when blowing at such a rapid rate. I wonder their balloon was not blown to pieces.

MR. P. — As the machine sailed along with the current there would be little resistance, and the aëronauts would scarcely feel any wind. Had the balloon been fixed, it would have been blown to pieces instantly. The force of the wind increases according to the squares of the velocity, so that when the velocity of the wind is doubled, its force is increased four times.

HARRIET. — What is the force of wind when it is blowing one hundred miles in an hour?

MR. P. — Such a wind, it is calculated, would act with a power of forty-nine pounds on every square foot of surface presented directly to its action.

HARRIET. — No wonder, then, that chimneys are blown down and trees uprooted by a high wind, if it have so much force. I am only surprised that more damage is not done.

Mr. P. — The wind does not often travel at so rapid a rate as one hundred miles an hour. It is estimated that what is termed a "high wind" travels at the rate of about thirty miles an hour, at which rate it would strike objects with a force of upwards of four pounds on every square foot. Those objects only whose surfaces are placed directly against the wind feel its full effect. If the surface be rounded, or placed obliquely to the wind, a great part of the force is lost, and the air is reflected obliquely from the object. In the same manner, when you throw a ball obliquely against a wall, it bounds off in a direction equally oblique, and does not strike the wall with nearly the force it would have done if thrown directly against it. — The subject of reflection is one well deserving of particular investigation, as it will serve to explain many phenomena of common occurrence; I shall, therefore, reserve it for a future occasion.

CONVERSATION XIV.

LIGHT.

Mr. P. — As I intend to explain to you, in the course of our present conversations, the nature of vision, it is advisable you should previously have some acquaintance with the properties of light, by means of which the organs of vision are brought into action. We cannot do better, therefore, than direct our attention to the subject this morning.

Robert. — Why, what is there to be said about light, father, that we do not all of us know already?

Mr. P. — There is a great deal more to be learned about it, Robert, than any one at present knows; and more, perhaps, than will be ever discovered by the mind of man. Even respecting the very nature of light philosophers are at fault; but it is generally supposed to be a material substance, composed of particles infinitely small.

Harriet. — Light a substance, papa! what, a thing that can be touched and handled?

Mr. P. — Material substances may exist which

it is impossible for you to handle. The air, for instance, is quite imperceptible to the touch, though its materiality can be rendered evident to the senses in other ways; yet air is supposed to be more dense, compared with light, than quicksilver is compared with air. The sun is the grand source of light, and it is imagined, by many, that the particles of light are constantly emitted from that body, which must, consequently, be daily diminishing in size and brightness; but the more generally received opinion is, that light exists throughout the universe as a separate elastic fluid, and that this fluid is brought into action by having a vibratory motion given to it, in some unknown manner, by luminous bodies. Respecting the nature of light, it must be acknowledged that we are in extreme ignorance; yet many of its general properties are well understood, and it is with these I wish to make you acquainted. Wise as you seem to consider yourself on this subject, Robert, I will venture to say, you can scarcely answer a single question respecting it. Can you, in the first place, tell me how fast light travels?

Robert. — Light travels! What is it you mean, father?

Harriet. — Why, Robert, you are puzzled at first starting: but do tell us, papa.

Mr. P. — It has been ascertained that light travels, or is communicated, from the sun to the earth in seven minutes and a half, which is at the rate of 192,500 miles in a second of time. This

is a degree of speed of which we can form no conception; for a body moving at that rate would travel eight times round the world whilst you were counting "one." The transmission of light from objects on the earth's surface seems, therefore, to be instantaneous; and an object is seen as soon as the light issues from it.

FREDERICK. — Does the light from other bodies, then, travel as quickly as that from the sun?

MR. P. — There is every reason to believe that it does.

HARRIET. — Do you mean, papa, such light as comes from the fire and from candles?

MR. P. — I mean, my dear, the light from all objects.

HARRIET. — What! do trees, and fields, and houses, send out light?

MR. P. — Yes, Harriet: you would not see them if they did not; nor should I now see you if every part of your face were not sending out rays of light to my eyes. The light, however, that proceeds from such objects is not their own, it is borrowed from the sun, or from other sources of light, and is reflected from their surfaces. The degree of this reflection varies according to the nature of the surfaces of the reflecting bodies, some of which reflect much more light than others. It is this difference in their powers of reflecting light that causes the difference in the brilliancy of objects. The greatest quantity of light is reflected

from a finely polished mirror, and the least from an unpolished black surface.

ROBERT. — But the surface of a looking-glass, placed in the light of the sun, appears almost black, excepting when you look in the direction of the reflection.

MR. P. — It does so, Robert; and the more perfectly the light is reflected, the darker does the reflecting surface appear, when not viewed in the line of reflection.

HARRIET. — But how can that be, papa, if, as you said just now, those things appear most brilliant that reflect the most light?

MR. P. — The difficulty will vanish, I trust, on a little further investigation into the properties of light. You must understand that the rays of light, by means of which all objects are seen, are of themselves actually invisible, unless received directly upon the eye; and that it is only when reflected directly to the eye that they become apparent.

HARRIET. — You seem determined to puzzle us this morning, papa; for the subject that Robert thought we knew so well appears to be the most difficult to understand.

ROBERT. — If we see the light coming from the sun, as I do now, how can it be said to be invisible?

MR. P. — I will try to convince you that it is so. Close the window shutters, Robert: there is a small hole in one of them, through which a ray

of light will be admitted, on which to make our experiments. (Robert *closes the shutters, and a beam of light from the sun shines in through the hole, and forms a bright spot on the wall.*) The light from the sun is visible now that it is reflected from the wall, but you cannot see it as it passes from the hole in the shutter to the wall.

Robert. — Yes, father, I see a streak of light all the way.

Mr. P. — I admit the direction of the light is perceptible; but what you see is not the direct ray of light itself, it is only the reflection of the light from the moats floating in the air of the room. If the air were perfectly transparent, you would not see any appearance of light between the wall and the shutter; and, on examination, you will find the light proceeds from small particles floating in the air.

Frederick. — Yes, I perceive it is so; the beam of light seems to be full of little moving things.

Mr. P. — It is those that reflect the light, as it strikes against them, and make the course of the ray perceptible. I will now place a piece of white paper for the sun's beam to fall upon, and you will perceive that the light in the room will be much greater than it is when reflected from the dark-coloured wall. (*Mr.* Powell *places the paper against the wall.*)

Harriet. — Yes, I can now see where you all are, very distinctly, which I could not do before.

Mr. P. — When I substitute a piece of black cloth for the white paper, a very different effect will be produced.

Harriet. — The room seems to be now all in darkness — I cannot distinguish any thing.

Frederick. — If you were to put a looking-glass in the ray, what would be the effect?

Mr. P. — We will try it. (*Mr.* Powell *holds a small plane mirror in the sun's beam, and directs the reflected light first against the wall, and then towards the hole in the shutter, through which the sun's rays enter.*) You perceive when the light is reflected against the wall the effect is nearly the same as when the direct light of the sun falls upon it; the spot of light appears rather less bright, because the whole of the light is not reflected by the glass. Now, however, that I direct the reflected light back again into the sun's beam, the room is in darkness. In these variations of the experiment, the same quantity of light entered the room, and the difference you noticed in its effect upon surrounding objects was produced by the difference in the surfaces from which it was reflected. I trust, therefore, that you are satisfied that light is of itself invisible, excepting when received directly upon the eye, or is reflected to it from the objects of sight.

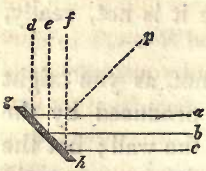
Frederick. — But what was the reason, father, of the reflection from the white paper producing more light in the room than the reflection from

the looking-glass? for I suppose it is not, really, so good a reflector as the glass.

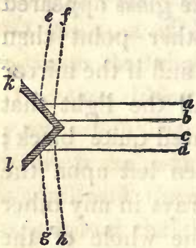
Mr. P. — No, my dear, it is not, as you might perceive from the bright spot produced by the reflection of the sun's light upon the wall; but the more perfect the reflector is, the more nearly does the light reflected resemble that which it reflects. The polished surface of the looking-glass being capable of reflecting most of the light thrown upon it, the reflected light had all the characters of the original rays, and did not become visible until again reflected from some other surface, whence the rays could be diffused to all parts of the room. As nearly all the light was reflected in one direction, the surface of the glass appeared dark when viewed from any other point than that in which the rays were sent; and if the mirror had been capable of reflecting all the light that fell upon it, it would have appeared quite black; because no light would have been left upon the surface of the glass to send out rays in any other direction than that in which the whole of the light would be reflected.

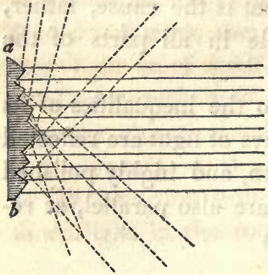
Frederick. — Then what is the cause, father, of the paper being visible in all parts of the room?

Mr. P. — It is owing to the inequalities of its surface. When parallel rays of light are reflected from a perfectly flat, smooth, and highly polished mirror, the reflected rays are also parallel, as re-



presented in this figure. Let *a b c* represent three parallel rays of light from a luminous body, striking against the plane mirror *g h*, and thence reflected in the directions *d e f*, according to the general laws of reflection, which shall be afterwards explained to you. These reflected rays, it will be seen, are parallel to one another, and would be visible only to an eye placed in the direction to which they are reflected; whilst an eye looking at the glass from the point *p* would see no light whatever. But when the rays of light fall upon an uneven surface, the effect is very different. Suppose *a b c d* to be parallel rays of light falling upon a polished angular surface, *k l*, some of the rays would be reflected upwards, towards *e f*, and some in the opposite direction to *g h*; and the result of reflection from a number of such angular surfaces would be the diffusion of the rays of light in all directions: as represented in this figure, in which the parallel horizontal lines are supposed to be rays, proceeding from a luminous object, striking upon the angular surfaces of the body *a b*; and the dotted





lines represent the varied directions into which the light would be reflected. The brilliancy of some kinds of spars is owing to the numerous crystals of which their surfaces are composed, by the disposition of which the rays of light are reflected to the eye from several of their polished angles at the same time.

Frederick. — I suppose then, father, that the objects in a landscape have the power of diffusing the rays of light in all directions, or else they would not be visible from every point of view, as they are.

Mr. P. — Exactly so. Most of their surfaces are sufficiently rough to spread the light all round them.

Harriet. — On a cloudy day, papa, when the sun cannot shine upon any thing, where does the light come from that is reflected in this way?

Mr. P. — The clouds, it is true, obscure a great part of the sun's light, but they are never so dense as to obstruct it altogether. The light of the sun, when it strikes upon the particles of moisture forming the clouds, is diffused through their whole mass; therefore the light we receive on cloudy days, instead of coming in parallel rays directly from the sun, is diffused among the vapours in the air, which thus become a great reservoir of light, and transmit it to the earth in various directions. Even on the clearest day, a great portion of the light from the sun is diffused by the vapours of the atmosphere. It is this dif-

fusion of the light that produces the bright appearance of the sky. Were the air to be perfectly transparent, the sky would appear almost black; because, as the rays of light are invisible, excepting when they strike directly upon the eye, if there were nothing above us that could reflect them, no light could be perceived, and the sun himself would appear like a brilliant orb surrounded by the darkness of night.

FREDERICK. — In very clear weather, then, I should suppose the sky must appear darker than it does when the atmosphere is full of vapour.

MR. P. — You are right, Frederick. In a fine dry climate the sky is of a much deeper blue than we ever behold it in this country; and at the tops of high mountains, above the misty exhalations of the earth, the sky appears of a still deeper colour. It is to the diffusion of light, by the vapours of the atmosphere, that we are indebted for the twilight that ushers in the day, and cheers its departure. In a perfectly transparent atmosphere we should be left in darkness the instant the sun was set; but the clouds and vapours reflect the sun's diffused light long after he is below the horizon, and during the summer months spread a genial twilight throughout the night.

CONVERSATION XV.

LIGHT (*continued*).

Robert. — By what means, father, are we able to distinguish any thing on a dark cloudy night, when no light can reach objects to be reflected from them?

Mr. P. — In the first place, Robert, I cannot admit the truth of your premises. There never was a night so dark as to be totally devoid of light. Indeed it may be doubted whether light could, under any circumstances, be absolutely extinguished, or, at all events, our senses will not enable us to say when there is no light.

Robert. — Not such a thing as darkness, father! What light can there possibly be in a room with the shutters and door closed, on a dark night, when there is neither candle nor fire?

Mr. P. — I cannot pretend to tell what quantity of light there may be in such a room; but that there is some light I may venture to affirm, though our eyes cannot perceive it. A certain quantity of light is requisite to enable us to dis-

tinguish the forms of objects, and a still greater to distinguish their colours: the absence of the smallest of these quantities we are accustomed to term a state of total darkness; yet, to other organs of vision, more delicately formed, this total darkness may seem as brilliant daylight. The eyes of beetles and mice, and of other creatures that make night their time of action, we must suppose to be so constructed as to enable them to see objects distinctly when they are to us invisible. Even the eyes of men, when they have been immured in the darkest dungeons for a number of years, have become so sensitive as to distinguish all the objects in their dismal abodes. An eye so accustomed to darkness suffers intolerable pain when again exposed to the light of day; and even in a dark night objects would appear perfectly distinct.

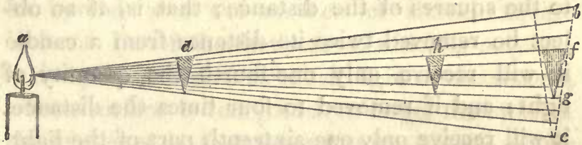
Frederick. — Then what we call darkness is only a diminished quantity of light; in the same manner as you explained cold to be but a comparative diminution of heat?

Mr. P. — You are right, Frederick. We judge of light and darkness by comparison; and what appears to be light one moment may appear as shadow the next, if a brighter light be contrasted with it. Even the flame of a candle may be made to appear as a shadow against the wall by the light of a brilliant lamp.

Harriet. — What makes a shadow against the wall seem so much larger when any thing is

held close to the candle than when it is held near the wall?

Mr. P. — The rays of light diverge from the flame of a candle in straight lines in all directions, in a smilar manner to lines drawn from the centre of a circle to its circumference. If, therefore, you place an object near to the flame it receives more of the diverging rays, and, consequently, obstructs more of the light, and a greater space of the wall appears in darkness than when it is held nearer to the wall. That this must be the effect will be rendered evident by this drawing;

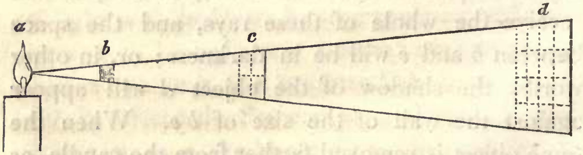


in which *a* represents the candle, and the diverging lines the rays of light issuing from it towards the wall. These rays, if there were no intervening object, would strike against the wall and illuminate the space between *b* and *c*. But when an opaque object is placed near the candle, as at *d*, it will receive the whole of these rays, and the space between *b* and *c* will be in darkness; or, in other words, the shadow of the object *d* will appear against the wall of the size of *b c*. When the same object is removed farther from the candle, as at *h*, many of the rays it before obstructed will pass over and under it, and illuminate parts of the wall that were before darkened by its shadow, and

the shadow will now be diminished to the size of *f g*.

ROBERT. — Then is there as much light upon a small object, when placed near to the candle, as there is upon the large space on the wall covered by its shadow?

MR. P. — Yes, Robert, there is. Light, when emanating from a point — as the flame of a candle may be considered — by diverging as it expands, diminishes in intensity in proportion to the space it illuminates. The diverging rays of light are known to diminish in intensity in an inverse ratio to the squares of the distance; that is, if an object be removed twice its distance from a candle it will receive only one-fourth the quantity of light; and if removed to four times the distance, it will receive only one-sixteenth part of the light. As it is of importance you should understand how this diminution of light is caused, I will make the subject more clear by a drawing. Here we have again a representation of the flame of a candle, *a*, sending out its diverging rays of light;



and the squares *b c d* we will suppose to be three square screens. The first one, *b*, we will imagine to be one inch square, the second to contain four

square inches, and the third sixteen. Let *b* be placed at a distance of one foot from the candle, *c* two feet from it, and *d* four feet. Now it is evident that the first screen, so placed, must obstruct all the diverging rays on their passage to the second, and prevent any light from falling upon it; that is, *b* will receive all the light which, were that screen not there, would come to the share of *c*. In the same manner the second screen, *c*, would rob *d* of all light from the candle, and it would receive on its surface, of four square inches, the same quantity of light which, if it passed on to *d*, would be spread over the surface of sixteen square inches. But if the first screen, which is only one inch square, receive as much light as the second, whose surface is four times as large, the light on the first must be four times as great as it is on the second screen, and sixteen times more intense than upon the third screen, on which the same quantity of light is spread over sixteen times the surface. The light of a candle would, in this manner, continue to diminish, till it would become at last invisible.

Harriet. — How far will the light of a candle reach, papa?

Mr. P. — It can be *seen*, on a clear night, at a distance of two miles; but there are no limits to the distance to which its light will really extend. If we allow the inhabitants of the moon to possess organs of sight sufficiently delicate to be sensible to the impression of light so attenuated, we may

imagine them to be able to read by the light of a candle burning, on a clear night, upon the surface of the earth.

HARRIET. — What a very droll idea! But if they could see the candle, they might see us, I suppose?

MR. P. — One supposition, my dear, is just as reasonable as the other. But, in point of fact, as we know of nothing that should totally obstruct the light of a candle on its course to the moon, we may reasonably conclude that its rays form a minute portion of the general mass of light which that heavenly body must receive from the earth.

HARRIET. — Does the moon receive light from the earth, papa, as we do from the moon?

MR. P. — Yes, my dear; and our globe must appear to the inhabitants of the moon, if inhabitants there be, a much larger and more brilliant orb than the moon does to us, in consequence of the earth being so much larger than the moon.

HARRIET. — But does the earth shine, papa, as the moon does?

MR. P. — Exactly in the same way — with light borrowed from the sun. The light we receive from the moon is not produced by any luminous property in that body, but is merely the light of the sun reflected to the earth from all the objects on its surface.

ROBERT. — But what can make them shine so? for our houses, and trees, and hills, don't shine.

Mr. P. — Yes, they do, or you would not see them. Every thing that sends out rays of light to the eye may be said to shine; but as their reflected light is dull, when compared with the light of the sun, we do not consider them as shining bodies. Even the moon ceases to *shine* after the sun has risen, and appears only as a circular white body, though she is then reflecting as much light to the earth as during the night, when she appeared so brilliant.

Robert. — But, father, you told us that light from all objects diminished four times whenever the distance was doubled, and that a screen placed four feet from a candle only received a sixteenth part of the light as the same screen when placed one foot from it, then how can the light reflected from the things on the face of the moon appear so bright at such a great distance?

Mr. P. — If you look again at this drawing of the screens and candle* it will explain the difficulty. In this drawing, you perceive that the screen of one inch square receives as much light as the screen containing sixteen square inches; but as the quantity of light is the same in both cases, the same quantity will be reflected from the large screen as from the small one, and it will make up in quantity what it wants in intensity. The same will apply to the moon. If we could approach within about two hundred and fifty

* Page 132.

yards of the moon, a circle of one yard diameter on her surface would then appear as large as her whole disc (which is two thousand one hundred and eighty miles in diameter) does when viewed from the earth; and as much light would be given out by that small circle, at that distance, as we receive from the whole orb. As we receded from the moon towards the earth, every time that we doubled the distance it would require a circle of twice the diameter (therefore four times the surface) to equal the apparent size of the moon's disc on the earth; and when arrived at our globe the whole surface of the moon would appear of the same size, and reflect the same quantity of light, as a circle of one yard diameter did at a distance of only two hundred and fifty yards.

Frederick. — Would a circle of a yard diameter on the earth give as much light, at a distance of two hundred and fifty yards, as the whole moon?

Mr. P. — Yes; a white circular board of one yard diameter, placed two hundred and fifty yards off, so as to reflect the direct light of the sun shining on it, would afford more light, at that distance, than is given out by the moon.

Harriet. — You don't mean, papa, that it would shine as the moon does?

Mr. P. — Yes, my dear, if we could see it, as we see the moon, when all other objects are in darkness.

Robert. — I can't see how that can be, father,

for the moon, on a clear night, seems to give nearly as much light as the sun.

Mr. P. — It is owing to the contrast between the light and darkness that makes you think the moon so bright. It has been ascertained that the light from the full moon is only about one hundred-thousandth part of that derived from the sun at noonday.

Harriet. — What is it, papa, that makes the man's face in the moon?

Mr. P. — The shadows on the moon's disc, that have been thought to bear some resemblance to the features of a man, are produced by the unequal reflection of the sun's rays from the earth and water on the surface of the moon; the darker parts are supposed to be the reflection from water, and the bright ones the reflection from land.

CONVERSATION XVI.

REFRACTION OF LIGHT.

Mr. P. — We will now consider another very important property of light — that of its refraction.

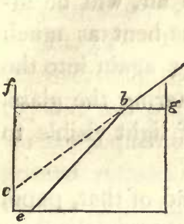
Frederick. — What is it you mean, father, by the refraction of light?

Mr. P. — The rays of light proceed from luminous objects in straight lines, and so continue as long as the transparent medium through which they pass remains the same; but when a ray of light enters *obliquely* into a different medium, (that is, if after passing through air it enters into glass or water, or after passing through the latter it enters into air,) it is bent from the direction of its former course; and this bending of the rays of light is termed its *refraction.*

Frederick. — Do the rays, after they have been bent in this manner, continue in a straight line in their new direction?

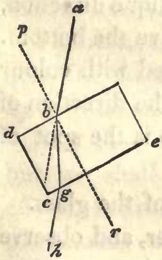
Mr. P. — Yes, whilst they pass through the same medium; but I shall make the subject more

clear to you by a drawing. Let *g e f* be a basin or glass full of water, and *a b* a ray of light striking against the surface at *b*, in the oblique direction *a b*. Its natural straight course, if the vessel were empty, would carry the ray to *c*; but as soon as it enters the water it is bent in a more perpendicular direction, and arrives at the bottom of the vessel at the point *e*, in the direction from *b* to *e*.



FREDERICK. — When light is refracted in this manner is it always bent more perpendicularly?

MR. P. — If the light pass from a rarer medium into one more dense, as from air into water, it is always refracted in a direction *nearer* to the perpendicular of the surface of the denser body. Thus, supposing *a b* to be a ray of light striking against a thick piece of plain glass, *d e* (the perpendicular to whose surfaces is *p r*), as soon as the light enters the glass it will be refracted in the direction marked by the line *b g*, which is nearer to the perpendicular of the surface of the glass than *b c*, its former direction. When a ray of light *issues* from a denser medium, on the contrary, the refraction takes place in a direction *farther* from the perpendicular of the sur-



face. Thus, in the figure before us, the ray *b g*, on issuing from the glass into the air, will be inclined towards *h*, and will be thus bent as much from the perpendicular, on coming again into the air, as it was bent towards it on entering the glass. I will now make the refraction of light visible to you by experiments.

HARRIET. — I shall be very glad of that, papa, for I am almost tired of looking at straight lines and *a b c*.

MR. P. — I will show you, first, the experiment I exemplified in our drawing of the vessel of water and the ray of light; to do which we must close the shutters, and admit the sun's light through the aperture only. (ROBERT *closes the shutters, Mr.* POWELL *having first procured a large glass tumbler and a jug of water; and when the shutters are closed he places the glass on the table in the direction of the sun's beam.*) You perceive the rays of light enter the glass in an oblique direction, and pass through its side a little above the bottom. I will fill it with water, slightly tinged with colour to enable you to see more distinctly the direction of the ray through the fluid. Where is the spot of light now, Robert?

ROBERT. — Quite at the bottom of the glass.

MR. P. — Look through the water, and observe where the light is bent by the refraction.

ROBERT. — I see that just where the beam of light enters the water it appears to be broken and bent down.

HARRIET. — (*Looking through the water.*) It is very curious: what makes it do so, papa?

MR. P. — The cause of refraction has not been discovered, my dear; for no attempt yet made to explain the phenomenon seems quite satisfactory: we are acquainted, however, with the laws which govern refraction, and are enabled to apply them to very important uses.

HARRIET. — What use can be made of refraction, papa?

MR. P. — If light were not subject to refraction we should not be able to make telescopes, microscopes, spectacles, nor any other optical instruments. The power of convex lenses, or magnifying glasses, depends entirely upon this property of light. So great is its importance, indeed, that did it not exist, we should not be able to see; and the beautiful machinery of the eye would be useless, if the rays that enter it were not refracted by its various lenses.

FREDERICK. — Can you explain to us, father, how the effect of magnifying glasses is produced by refraction.

MR. P. — I will do so at a future opportunity; but we shall now confine our attention to the effects of refraction, as exhibited to us in the natural phenomena around us.

ROBERT. — Is light refracted in the same degree, on passing through all transparent substances?

MR. P.— No, my dear: the degree of its refraction varies according to the difference

in the densities between the refracting medium and that through which the light first passes. Light, in passing from air into water, is refracted one-fourth nearer to the perpendicular than its former direction; and in passing from air into glass it is refracted one-third nearer. The rays of light, in passing from a vacuum into air, are also refracted from their original course; and it has been discovered that the light from the sun, and from the other heavenly bodies, is thus refracted on coming to the earth, and that we consequently never see them in their true positions in the heavens. Owing to this refractive power of the atmosphere, we see the sun several minutes before his direct rays would reach the eye; and his image, from the same cause, remains in sight some time after he is really sunk below the horizon.

ROBERT. — How can that be, father?

MR. P. — The experiment I have just shown you will explain the matter clearly. The beam of the sun's light you observed passed through the side of the glass before it was filled with water, and would, therefore, not be perceptible to an eye placed at the bottom, until the sun rose higher in the heavens, and threw his beams directly on the bottom of the glass. But when the water was poured in, the rays were bent down to the bottom, and the sun would become visible from that point. The water, in this case, represents the effect of the atmosphere of our earth, which thus draws down the rays of the sun's light from their original

course, and renders him visible before his rays would otherwise reach the eye.

FREDERICK. — Do we see the sun and the stars in their true position, or do they seem to be in the direction in which their rays are refracted to us?

MR. P. — All objects appear to be situated in the direction from which the rays proceed to the eye; therefore, the sun and the stars appear to us to be higher in the heavens than they really are. We will now reverse the order of our experiment, and let the light proceed from an object at the bottom of the basin, through the water, into the air. An eye, placed so as to look into the glass in the direction that the sun's beam entered it, will not, whilst it is empty, see any object at the bottom; but when it is filled with water the bottom of the glass will appear to be raised, and an object placed there will become visible.

HARRIET. — I should like to see that very much.

MR. P. — Very well, Harriet, you shall soon be satisfied: it will be better to substitute a basin for the glass, else you would see through the sides, and the effect would be destroyed. (*Mr.* POWELL *fixes a wafer at the bottom of a white basin, and* HARRIET *stands at such a distance from it as to lose sight of the bottom. Mr.* POWELL *then fills the basin gently with water.*)

HARRIET. — As you pour in the water, I see the bottom part of the basin gradually rising — and now I see the wafer: it appears nearer to the top than it was.

Mr. P. — You may learn from this experiment that rivers and ponds are really deeper than they seem to be, owing to the refraction of the light proceeding from the objects at the bottom; which, therefore, appear to be nearer to the surface than they are. From the same cause objects in water appear not only different in position, but different in shape. I dare say you have often observed that when you put a stick into water it seems to be bent as if it were broken.

Frederick. — Yes, I have very often, and it has always puzzled me. I shall know how to account for it in future, by the refraction of the rays of light as they proceed from the stick through the water into the air.

Mr. P. — Very good. You may repeat the experiment with the basin of water and the wafer by yourselves: it is a striking illustration of the effects of refraction. The experiment may be varied, by fixing two or more wafers at the bottom, so that they may become visible one after the other.

CONVERSATION XVII.

COLOURS.

Robert. — You told us, father, the other day, that the light from such objects as trees and houses is the light of the sun reflected from them; but I have been thinking that it must be something else besides the light of the sun; for almost every thing we look at is of a different colour, and the sun's light is no colour at all.

Mr. P. — The difficulty you have started, Robert, evinces a reflective and philosophic mind, which I trust you will cultivate to advantage. It was taken for granted, previous to Sir Isaac Newton's discoveries on the subject, that light was, as you conceive it to be, without colour; and several curious explanations were attempted by ancient philosophers to account for the colour of bodies. Some imagined it to be a flame issuing from them, whilst others affirmed that the different colours were produced by different motions communicated to the particles of light. We are indebted to Sir Isaac Newton for the discovery, that the light which emanates from the sun, though

apparently so colourless, is really composed of all the colours mingled together.

ROBERT. — What, father, the white light of the sun full of colours! I cannot think how it is possible.

MR. P. — If we admit the sun's beam through the aperture in the shutter, as in our former experiments, I can separate the colours of which it is composed, and show them to you.

HARRIET. — I am quite anxious to see how you can do so. (FREDERICK *and* ROBERT *close the shutters, and Mr.* POWELL, *having provided himself with a glass prism, places a sheet of white paper against the wall to receive the rays of light.*)

MR. P. — This long triangular piece of glass is called a prism, and its angular shape enables it to refract the rays of light passing through it very far out of their original course. When I place the prism so as to intercept the light on its passage to the screen, the round spot of light will become oblong, and be tinged with brilliant colours.

HARRIET.—The white light is gone; but, higher up the screen, I see all the colours of the rainbow.

MR. P. — What you now see is the same bright light dissected into the different parts of which it is composed. The colour at the bottom is red, the next to it is orange, above that is yellow, and then come green, blue, indigo, and violet, in succession, above one another. Sir Isaac Newton concluded, from this and from other experiments, that the light of the sun is composed of a mixture

of coloured rays, some of which are more easily refracted than others; and that when a beam of light is very much bent, as is the case when it passes through a prism, the rays most refrangible are separated from those that are less so. The white light is thus divided, and the several colours of which it is composed are exhibited separately. The image of the sun's light, so dissected, is termed the *solar spectrum*.

Robert. — Do you mean, father, that if all those colours I now see were mixed together, they would become white?

Mr. P. — Yes. When all the coloured rays are collected together by a convex lens, or burning glass, the light will be colourless. Observe, now that I hold this lens between the prism and the paper, at a proper distance, the coloured rays are brought to a point, and appear as a bright spot of pure white light.

Robert. — I am quite surprised to see how all the colours have disappeared.

Mr. P. — The same effect may be produced by painting the colours of the solar spectrum, in their proper proportions, on the upper part of a top; and when it is put in rapid motion, the colours will be blended together and appear white.

Harriet. — How many colours are there in light, papa?

Mr. P. — The prism, you perceive, divides it into seven, of which red is the least refracted, and violet the most. Four of the seven, however, may

be considered as merely mixtures of the other three, and the real primitive colours are red, yellow, and blue. With these, in different shades and proportions, all colours may be made.

FREDERICK. — I do not yet understand, father, what causes the sun's light, when it is reflected from an object, such as a house, to appear of a different colour from the light that strikes against it.

MR. P. — It is supposed that, owing to some peculiar disposition of the particles composing different substances, they possess the power of separating the rays of light into its component colours. Some of the colours are then absorbed by the substance against which the light strikes; and those which it has not the power of absorbing, are reflected from its surface. Thus, a brick house is said to absorb all rays excepting the red; the red one it reflects to the eye, and we, therefore, call such an object red. Trees and fields, again, reflect the green rays (which are a mixture of the blue and yellow), and absorb the red.

FREDERICK. — As the colours of the rainbow are so much like those produced by the prism, I suppose they are formed in the same manner, by the separation of the rays of the sun's light.

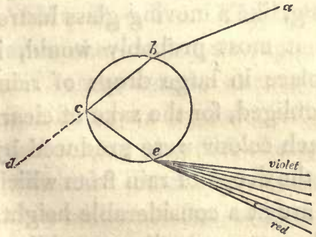
MR. P. — Yes, my dear, they are. When raindrops are falling from the clouds, at the time the sun is shining upon them, part of the sun's light is reflected from the back of the drops to the earth.

ROBERT. — *Reflected* from the transparent drops of rain, father?

Mr. P. — Yes, Robert, reflected. No substance is sufficiently transparent to permit all the light to pass through it; and when light strikes very obliquely against glass or water, nearly the whole of it is reflected, and none transmitted. The reflection of the sun's light from a window, and from a glass of water on the table, are instances of partial reflection from the surfaces of transparent bodies.

Frederick. — A drop of water, too, looks bright and sparkling in almost any direction; is not that owing to its reflecting the rays striking upon it?

Mr. P. — It is a very appropriate illustration, Frederick. If the drops of rain that reflect the coloured bow were flat, instead of being round, the light would be reflected from them to the earth, without being divided into its prismatic colours, and the rainbow would appear as a glittering arch of pure light: but the drops being circular, the inclinations of the surfaces at which the light enters, and from which it is afterwards reflected, are so oblique, that they bend the light so much as to separate them; and it is, therefore, reflected to us in its variegated colours. Suppose, for instance, *a b* to be a ray of light entering a raindrop; it would be refracted to *c*, and



part of the light would pass out of the drop towards *d*; but as it strikes at so oblique an angle, the greater portion of the light would be reflected to *e*. On re-entering the air, the ray would undergo another refraction, and be separated into its different colours; the red rays being at the bottom, and the violet at the top, as here represented.

Robert. — But if the coloured rays are spread so much, how can the eye take them all in at once?

Mr. P. — You forget, Robert, that there are drops of rain following each other, in rapid succession, from the clouds to the earth; and that this refraction and reflection are going on in each. If, therefore, the eye were so placed as to receive the red ray from this drop, it would receive the orange ray from the drop below, and the yellow from the drop below that, and so on, until it received all the colours of the rainbow from successive drops.

Robert. — Then, if the light come from so many falling drops, a rainbow ought to be always sparkling and glittering, like a moving glass lustre.

Mr. P. — And so it most probably would, if the refraction took place in large drops of rain. Though I have been obliged, for the sake of clearness, to speak as if each colour were produced by a single drop; yet, as the drops of rain from which the light is refracted are at a considerable height, the drops must be there very small, resembling,

perhaps, the minute particles of water visible in a mist. The *depth* of each stratum of colour in the rainbow, therefore, as well as throughout the extent of the arch, may be the result of refraction and reflection from numerous very small drops of rain, the rays from which become so blended together as to produce uniform colour. In this manner we may conceive that the seven prismatic colours seen in the rainbow may proceed from hundreds of minute drops, above one another, instead of from only seven, as frequently supposed. There is sometimes a second bow formed above the first, in which the colours are reversed. This bow is produced by the refractions and reflections of rays entering the lower part of the drops. These rays are twice reflected at the back of each drop before they issue from it, when they are again refracted into the prismatic colours. In consequence of the light lost by the two reflections, this second bow is generally very faint.

Frederick. — Is the halo that is often seen round the moon produced in the same way as the rainbow?

Mr. P. — Yes. The light of the moon, shining upon the condensed vapours of the atmosphere, will, under certain circumstances, be so much refracted as to separate into its prismatic colours, and form a beautiful circle, through the centre of which the direct rays of that heavenly body penetrate with unsullied brightness to the earth.

Robert. — You told us, father, that all the

colours were contained in light, but you have said nothing about black.

Mr. P. — I thought you would have understood, from what had been previously said, that black is merely the absence of light; the difference between black and white is, that white *reflects all* the rays united, and black absorbs them all and *reflects none*.

Robert. — Then, if black do not reflect any light, how can it be seen by the eye?

Mr. P. — By its contrast with surrounding objects, from which light is reflected. If a black body be placed on a white ground, for instance, the eye receives light from all parts immediately round it, and the absence of light from the black object renders its outline even more distinctly marked than if it sent out rays. It is in the same manner we distinguish a shadow. If you hold your hand between the candle and the wall, you perceive a distinct outline of the hand upon it, which is marked by the comparative absence of light on those parts of the wall where the light of the candle is intercepted; and the outline is more distinct than it would be if the form of the hand were painted in any transparent colour upon glass, and held in the same situation, because the contrast between the light and comparative darkness is greater than between the light and the colour which sends rays to the eye.

Robert. — Then black, which seems the strongest of all colours, is no colour at all!

FREDERICK. — And white, which seems to be no colour, is all colours combined!

HARRIET. — What you have told us about colours and light, papa, is quite contrary to the ideas I before had about them.

MR. P. — There is no branch of science which deludes the senses so much as that connected with light and colours. The most extraordinary deceptions can be produced by a proper disposition of colours, combined with the effect of light and shade. The exhibition of the Diorama affords a most beautiful example of this; and by having a contrivance for diminishing and increasing the light upon particular parts of the painting, the effect produced is perfectly wonderful.

HARRIET. — Yes, papa; I remember, when you took us there, I could not believe that what we were looking upon was only a flat piece of canvass.

MR. P. — It is, indeed, difficult to conceive that the objects painted on the canvass are not realities. The eye is still more easily deceived by colours than by the forms of objects. There are some persons who cannot even distinguish one colour from another, and make very curious mistakes in consequence. A gentleman residing in Derby, who had this peculiar defect of vision, went to his tailor to order a suit of mourning to attend the funeral of a friend, and when shown the card of patterns, to select his cloth, he unfortunately fixed upon a brilliant red. The tailor supposed he wanted the dress for a fancy

ball, and, without hesitation, made up the suit and sent it home, according to order. On the morning of the funeral, a friend of the gentleman's luckily called in to accompany him; when, to his amazement, he beheld the mourner make his appearance accoutred from head to foot in his splendid suit of red. The effect was rendered the more ludicrous by the serious face and unconscious manner of the gentleman; nor could he understand why his friend looked so astonished; and it was with difficulty he could be convinced of the impropriety of going to the funeral in a dress he had ordered expressly for the occasion.

Harriet. — I never heard of any thing so strange. Had the gentleman chosen blue, I should not have wondered, for I often see people with blue coats and gowns, which they imagine to be black.

Robert. — If persons were to be dressed in perfect black, they would be, or rather they ought to be, invisible, — ha, ha!

Mr. P. — You may laugh, Robert; but so they would be, if there were a back-ground equally black behind them. I have seen a very good deception produced in this way on the stage. The figure of a skeleton was painted on a black dress fitting very tight to the body of a man, who was enveloped in a long black cloak. When he spread out his arms and disclosed himself, the real outline of his figure was invisible, as there

was nothing to contrast with it, and there appeared only the form of the skeleton, which seemed to be endowed with life.

Harriet. — How very frightful it must have looked! If the skeleton had not been painted on the black dress, I suppose you could not have seen any thing of the man when he opened the cloak.

Mr. P. — No; he would have been perfectly invisible, as Robert conceives every one ought to be who is dressed in a colour that absorbs all the light.

CONVERSATION XVIII.

REFLECTION.

Mr. P. — I dare say, Harriet, you have often looked at yourself in the glass; — can you tell us the cause of your seeing yourself there?

Harriet. — No, indeed, papa; I never thought of it: I should like very much to know.

Mr. P. — The effect is produced by the reflection of the rays of light from the polished surface of the mirror.

Frederick. — How can the reflection of the rays of light produce such an effect?

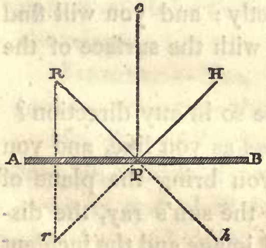
Mr. P. — When light strikes against a polished opaque surface, it is reflected, or sent back, in the same manner that all elastic substances, when striking against one another, rebound, or are reflected. Thus, when Harriet looks at herself in the glass, the rays of light proceeding from all parts of her face strike upon the mirror, and are sent back, or reflected, towards her again; and her eyes receive the reflected rays from the glass, and form them into an image of herself.

Robert. — But how is it that I can now see Harriet in the glass, though we are neither of us before it?

Mr. P. — That, also, is owing to the reflection of her image by the glass. The rays from her face strike against the glass at an angle of about 45° from the perpendicular of its surface, and they are reflected towards you at the same angle on the other side the perpendicular; therefore you see her image, though she cannot see it herself. She is also able to see you, from the same cause.

Frederick. — Are the rays of light always reflected at the same angle at which they strike the reflecting surface?

Mr. P. — Yes, that is the rule which governs all reflections. I shall, perhaps, make the subject more intelligible by this drawing. The line A B represents the mirror; H is the point where Harriet stood; R is Robert's position; and the dotted line P *c* is the perpendicular drawn from the surface of the glass. Now, those rays of light from Harriet's face, falling on the glass in the direction



H P, were reflected at an equal angle on the other side its perpendicular, that is, in the direction P R; and Robert, looking in the same direction towards the point P, would see Harriet's

image, apparently behind the glass, at *h*. The rays from Robert's face would, in the same manner, be reflected in the direction P H, and Harriet would see his image behind the glass at *r*. The angle at which the rays of light fall upon the plane of the reflector is called the *angle of incidence*, and the angle at which they are reflected is called the *angle of reflection:* these angles are always equal to one another. Now that the sun is shining into the room, I can show you that the angle of incidence and the angle of reflection are equal. You see the ray of the sun's light strikes obliquely on the table at an angle of about 30°. Frederick, place the small looking-glass flat on the table, and notice where the reflection will be.

FREDERICK. — There it is, on the ceiling, at the farther end of the room.

MR. P. — You can perceive, by the motes in the sunbeam, the directions of the incident and of the reflected rays distinctly; and you will find that the angles they make with the surface of the glass are equal.

ROBERT. — Will they be so in any direction?

MR. P. — Raise the glass as you like, and you will find that the nearer you bring the plane of the glass perpendicular to the sun's ray, the distance between the reflected image and the incident ray will diminish.

FREDERICK. — Yes, look! as I raise the glass, the bright spot on the ceiling moves nearer to the

window; and now it is entirely lost in the sun's ray.

Mr. P. — The light from the sun now strikes directly, that is, perpendicularly, against the glass, and is reflected into itself, as the image of Harriet is when she is admiring her own face. When the rays struck the glass obliquely, and were reflected to the ceiling, they were in the same relative positions to the glass as Robert and Harriet were when they saw each other.

Harriet. — Last evening, papa, I was very much surprised to see what I thought was a large fire in the road; but on going to the window to look, I found that it was nothing but the fire in the room that I saw.

Mr. P. — The deception was produced by the rays of light from the fire striking against the window, which reflected them to you at the other end of the room, in the same manner that the rays from Robert's face were reflected to you by the mirror.

Harriet. — Yes, but, papa, there was no looking-glass near the window.

Mr. P. — All glass, however transparent it may be, reflects a portion of the light that falls upon it; and when the rays strike upon a pane of glass very obliquely, most of them are reflected; as I mentioned to you yesterday in explaining the rainbow.

Harriet. — Then why is not the fire reflected

by the glass in the day-time, as well as in the dark?

Mr. P. — It is so; but the rays of light from the objects outside the window enter the glass during the day, and, being more vivid than the partially reflected rays from the fire, obscure them.

Harriet. — But how was it, papa, that the fire appeared to be in the road?

Mr. P. — The image in a plane mirror, or reflector, always appears to be in the direction that the reflected rays enter the eye, and to be as much behind the glass as the object is before it. It is one of the laws of reflection from plane mirrors, that images appear to be formed on an ideal line drawn perpendicular from the objects to the surface of the reflector. Thus, you observe, in the drawing, the point *r*, where you would see Robert's image, is on a line R *r*, drawn perpendicular to the surface A B. When you looked at Robert in the glass, he appeared to be behind it; but you knew from experience that he was not; and the other objects in the room being also reflected, tended to destroy the illusion. In the case of the fire, the deception is greater, in consequence of the reflected rays from it alone being visible, as the rays from the other objects in the room would not be sufficiently vivid to be seen.

Frederick. — Do not you remember, Harriet, when we were little children, trying to catch ourselves behind the looking-glass? Nothing puzzled

me so much as to find the image gone when I looked behind.

Harriet. — Yes, I recollect it very well; and, not long ago, I was quite deceived, when at the Bazaar in Soho Square, by the reflections in the large mirrors placed against the walls: I thought one was an open door leading into another magnificent room, and I should have walked against the glass if I had not been held back.

Mr. P. — Since the invention of that elegant instrument, the kaleidoscope, by Dr. Brewster, the effect of which depends upon reiterated reflection, more attention has been paid to the reflections from plane mirrors; and nothing produces so pleasing and deceptive an appearance as a series of them well arranged.

Frederick. — Are all elastic bodies reflected in the same manner as light?

Mr. P. — Yes, their reflection is governed by the same laws; the reflection being always at the same angle at which they strike the reflecting body. In addition to those properties of light which we have now considered, discoveries have been made respecting its nature, and the circumstances attending its contact with and transmission through solid bodies, that seem to open a wide field to philosophical investigation. The polarisation of light, the inflection or diffraction of light when passing near the edges of bodies, and the effect of the interference of light when rays cross each other, though highly interesting as subjects

of scientific research, have not as yet, however, been sufficiently connected with the commonly observed phenomena of light to render them fitting subjects for our present notice. The nature and properties of light that most affect the appearances of objects around us are those which I have explained to you, viz. its composition of coloured rays, its refraction and reflection.

CONVERSATION XIX.

VISION.

Frederick. — Since you explained to us yesterday, father, the reflection of light, there is one thing I have thought of that I do not understand. When the rays of the sun, or the light of the fire, are reflected by a looking-glass against the wall, I see nothing but a square bright light, the shape of the glass; but if I let the reflection come into my face, I see the image of the sun quite round, and distinguish the flames of the fire.

Mr. P. — I am not surprised at your being puzzled by the different appearances the rays present, when reflected directly on the eye, and when the reflection is thrown on the wall: I will endeavour to explain the difficulty. I have before told you that the rays of light from the sun, and the rays reflected from any visible object, proceed from all parts of the object in straight lines; and that there is no point on which the light falls, however small it may be, that does not receive

rays from every part of the object. Thus, there is no point of the wall illumined by the fire, that does not receive rays from all parts of it at the same time. The light on the wall may, therefore, be considered as composed of innumerable small images of the fire, which are all blended together, and assume an appearance of uniform light. When any portion of these mingled rays from the fire is reflected, from the surface of a plane mirror, upon the wall, the only effect produced is to increase the light in that part, by the addition of the quantity of light reflected by the mirror; the rays of light being as much mingled together as before. But, if you place your eye in a position to catch the reflected rays, all the small fires of which the light is composed are brought, by the lenses of the eye, to one point, and there form a distinct image of the fire.

FREDERICK. — Then the light on the wall is the same as that which enters the eye, and the difference in appearance is produced by the eye itself?

MR. P. — It is: I can show you the manner in which this effect is produced, by placing a convex lens, or magnifying glass, between the fire and the wall. But you must first close the window-shutters, else the rays of light entering from without will overpower the light from the fire. (FREDERICK *and* ROBERT *close the shutters.*) You perceive, as I hold the glass near the wall, it intercepts the light; and as I bring it nearer to its focus, you

may see a distinct inverted image of the fire on the wall.

Harriet. — Does the glass collect all the little fires together, to form that one?

Mr P. — Yes, my dear, all the mingled rays from the fire are collected by the glass towards separate points, and that is called bringing the rays to a *focus*. I shall explain how this effect is produced by lenses at another time.

Frederick. — Does the eye bring the rays to a focus in the same way as a lens?

Mr. P. — Yes; the eye is composed of lenses, of different degrees of convexity and hardness. The *crystalline lens*, which is the principal one, exactly resembles in shape a double convex lens, or common magnifying glass. By means of these lenses, the rays of light proceeding from all visible objects are converged to a focus at the back of the eye. The same effect may be shown by holding a small lens at the end of the room before a white screen, when we shall see the objects outside distinctly marked on the screen, though much diminished. (*Mr.* Powell *holds the lens at its focal distance from the screen, so as to throw the image upon it.*)

Harriet. — Yes, papa; I see the houses, and the people walking in the road; but they are all topsy-turvy, and the men seem to be walking on their heads.

Mr. P. — You must understand, that the houses and other objects in the street give out rays of

light during the day, as well as the fire; and the light on the wall of the room is produced by an innumerable quantity of the rays from the houses, sky, &c. Now, when I place the lens between the window and the wall, the surface of the glass receives a number of these rays, which are converged by it, and formed into the image you see.

Frederick. — But I suppose, father, the objects are not shown upside-down at the back of the eye?

Mr. P. — Yes, they are indeed.

Robert. — What! do you mean, father, that I see people standing on their heads, and trees growing with their roots upwards?

Mr. P. — No, Robert, *I* do not mean to say so; but there are few writers who treat on this subject who do not.

Robert. — Do they seriously say that men see every thing in the world upside-down?

Mr. P. — They are quite serious.

Frederick. — Then how can they account for my seeing Robert and Harriet standing on their feet, if my eyes see them with their feet uppermost?

Mr. P. — To get over that difficulty, it is said that infants find, by feeling at different things, that what seems to them to be the top, is, in fact, the bottom; and that so, by experience, we get accustomed to refer all objects to a different position from that in which they are seen.

Harriet. — But do little children, then, really see their mammas and nurses with their heels uppermost? How very droll it must be!

Mr. P. — There is no reason to believe that they do; but as it was taken for granted that the images must be seen inverted, because they were so at the back of the eye, there was no other means of accounting for their appearing upright, than by supposing we corrected the inverted position by experience when young.

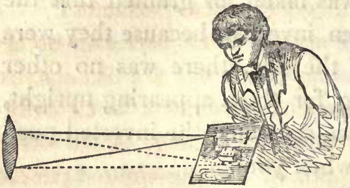
Frederick. — Then how do you account, father, for our seeing things upright, if the images be inverted at the back of the eye?

Mr. P. — The retina, on which the inverted image is formed, is an expansion of the optic nerve; which nerve conveys the sensation on the retina to the brain. No one supposes that the *retina* sees the object; it is only a screen on which the image is formed. It seems, therefore, surprising, that it should have ever been inferred, from the single fact of the image being inverted on this screen, that the objects must be seen in an inverted position by the mind.

Robert. — But how can the mind change the position of the image on the screen at the back of the eye?

Mr. P. — The inverted picture formed by the lens on the paper screen will solve the difficulty at once. You observe that, when you look at the screen in front, the houses appear inverted; but go behind the screen, and *look down* upon the inverted picture. Now, Robert, how do the houses seem?

ROBERT. — (*Looking down upon the screen, as represented in the woodcut.*) Just as they ought to be; and the people are walking very properly on their legs.



MR. P. — The houses still appear to me to be inverted; but the position of the objects to you is changed by your seeing them from a different point of view. In the same manner we may imagine the mind *looking down* upon the inverted image on the retina, and viewing it in an upright position. As we can form no conception as to the manner in which the sensation of sight is produced in the brain, and as there is really no more difficulty in supposing the objects are seen upright, than in the supposition that they are seen inverted, it seems absurd to conclude that they are seen in a position the reverse of their real one; it is gratuitously inventing a difficulty, for no object whatever. The inverted theory, too, is contrary to that simplicity and harmony of arrangement that is always perceptible in the works of Nature; and it ought to have been received with great doubts on that account alone.

ROBERT. — I do not think I should ever have believed the topsy-turvy plan of seeing things upright; and I am very glad, father, that you do not.

FREDERICK. — What is the reason, father, that

some people are short-sighted and others long-sighted, and are obliged to wear spectacles?

Mr. P. — In the eyes of those persons who are near-sighted, the lenses of the eye are too convex, and collect the rays of light into a focus before they arrive at the retina; the image is, therefore, formed indistinctly upon it. In long-sighted people, on the contrary, the lenses of the eye are too flat, and do not bring the rays to a focus soon enough. To correct these defects of vision the near-sighted person must use concave glasses, and the long-sighted person must use glasses that are convex. We can see the effect of these different glasses on the inverted picture produced by the lens on the screen. (*Mr.* Powell *holds the lens at its focal distance from the screen.*) You see the image of the houses is now perfectly distinct, for the screen is placed in the focus of the lens. I will remove the glass a little farther from it.

Harriet. — The houses and people seem now to be all confused.

Mr. P.—That is the appearance which objects present to those who are near-sighted. The rays are brought to a focus before they reach the screen; as you may perceive on placing a piece of paper about half an inch from it.

Harriet. — (*Holding a piece of paper in the focus of the lens.*) Yes, here I see them all again, quite distinctly.

Mr. P. — I will put a concave glass close to the lens, and you will find that it will make the picture

on the screen again distinct. You perceive it is now clear.

Robert. — How does the concave glass produce this effect?

Mr. P. — You must know, my dear, that the length of the focus of a glass depends upon its convexity or roundness, the focus being nearer to the glass when the convexity is the greater; and the flatter the surfaces of the glass are, the greater is the distance of the focus. A concave glass, on the contrary, instead of bringing the rays of light to a point, after passing through it, spreads them farther apart, and the deeper the hollows of the concave surfaces the more will the rays be separated. Therefore, the effect of the concave glass is to separate the rays of light as they are converging towards a point, and to prevent them from coming to a focus so near the lens. If the hollows or concavities of the glass exceed the convexity of the lens, the rays would not come to a point at all.

Frederick. — I suppose, if instead of the concave glass you were to use another convex one, the rays would come to a point sooner than before?

Mr. P. — Yes; and it is upon that principle that people who are long-sighted correct the defect. They use convex glasses, and by this means the rays of light, that were not sufficiently converged by the lenses of the eye, are brought to a focus on the retina. As the rays of light, pro-

ceeding from objects near the eye, diverge more than the rays issuing from more distant ones, all objects would have appeared confused, except when viewed at a certain distance, if the eye had not the power of adapting itself to the different circumstances under which it receives the rays of light. To accomplish this end it possesses the faculty — either by varying, to a certain extent, the convexity of its lenses, or their distance from the retina — of adjusting itself according to the divergence of the rays, so as to form the images of objects distinctly on the retina, at all distances exceeding five or six inches.

HARRIET. — The formation of the eye seems to be as complicated as that of a telescope.

MR. P. — It is the most astonishing piece of mechanism ever beheld, and is most admirably adapted in all its parts to the uses for which it is intended. Light, by which all things are rendered visible, is inexplicable to us in its nature and mode of operation: we know that it is reflected from all objects, and that they thus send their borrowed rays to the eye — it is, by some unknown means, refracted by lenses so adjusted in the ball of the eye as to concentrate the rays on the retina to a focus — the retina is spread out as a screen, peculiarly well adapted to receive the images that the lenses throw upon its sensitive fibres — the optic nerve conveys the impression, by some inscrutable process, from the retina to the brain, there to excite in the mind, in some manner totally beyond our

comprehension, the sense of sight. Had one link of the chain been wanting, the rest would have been useless. The organs of sight could not have been brought into action without the existence of light, and light itself would have been valueless if not endowed with the properties of reflection and refraction. And when we admire the wisdom which created the organ, we must not overlook the beneficent provision for the continued performance of its functions, and the care with which it has been secured from injury. The secreted humours of the eye preserve its proper form and maintain its transparency; whilst the bony socket, the shadowing eyebrow, the curtaining lid, and the sensitive eyelash, secure it from violence, protect it from injury, and warn it from danger.

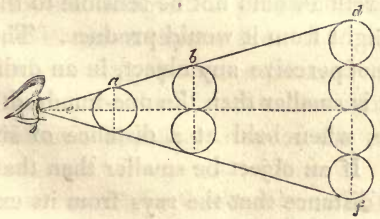
CONVERSATION XX.

VISION (*continued*).

Mr. P. — Did any of you ever consider the cause of objects appearing so much smaller when seen from a distance than when viewed near?

Frederick. — I have often wondered at their doing so, but I could never find out the cause.

Mr. P. — The apparent size of objects depends upon the angle which the rays of light, issuing from their extreme points, subtend on entering the eye; and as the rays which proceed from the top and bottom of an object, when near, enter the eye at a much greater angle than when it is at a distance, it appears proportionably so much larger, as this drawing will show. Balls of the same size are here supposed to be placed at different distances from the eye at *e;* those at *b* being double the distance of the one at *a*, and those at *d* being double



the distance of those at *b*. It is evident, that the rays of light from the two extremes of the four balls ranged in a straight line at *d f*, must proceed to the eye in the direction *d e* and *e f*, forming the angle *d e f*. Now two of the same balls placed at *b* will obstruct those rays, and hide all the four balls, and will appear to occupy as much space as the four. Again, the single ball at *a* will conceal all the others, and will consequently seem to occupy as much space as the four at *d f*, and as the two at *b*; therefore, the same ball placed at *a* will appear four times larger in diameter than when placed in the line *d f*, which is four times the distance from the eye.

FREDERICK. — And if the ball were removed farther off, I suppose it would appear less and less, in the same proportion, till it was out of sight.

MR. P. — Yes, it would.

ROBERT. — I should suppose the ball might be seen, however far off, if the day were clear, and there was nothing to hide it.

MR. P. — No, Robert, it could not; for, at a certain distance, the angle subtended by the extreme points of the ball to the eye, would be so minute that the retina would not be sensible to the impression the light from it would produce. The human eye cannot perceive any object, in an ordinary light, that is smaller than the one-hundredth part of an inch, when held at a distance of six inches from it. If an object be smaller than that, or be at such a distance that the rays from its ex-

treme points do not occupy, when at a distance of six inches from the eye, a space equal to the one-hundredth part of an inch, it will be invisible. The figure of a man is so much diminished by distance as to be invisible to the naked eye four miles off; for then the rays from his head and feet are so close together as to be covered by the point of a pin.

Robert. — But if the same thing placed near the eye appears as tall as a much larger one at a distance, how is it that we do not mistake them to be really of the same size?

Mr. P. — It is owing principally to the diminution of the quantity of light as objects recede. I suppose I need not remind you that the light from an object decreases four times in quantity when the distance is increased only twice, * and that it becomes less and less, in the same proportion, the farther it recedes. Now we know, by experience, that the sizes of objects diminish as they are removed from the eye; therefore, when we see a person with whom we have been talking walk away, we do not imagine that he grows less as he departs, but attribute his apparent decrease in size to his being at a greater distance than before. We can compare him also with other objects whose size we are acquainted with; and as they are diminished by distance equally with himself, he still appears to be of the same relative size,

* See Conversation on Light, p. 132.

however much the apparent magnitude of his figure is lessened. And again, as his person recedes from view, the light from it decreases in fourfold proportion to the distance, and we are therefore accustomed, by connecting together the two circumstances of size and brightness, to conceive what impression a man of his size, at such a distance, must produce on the retina. If we saw the same person approaching at another time, when there were no objects to compare him with, we should thus know, from the impression he produced, that he was really taller than a child close at hand, who might seem to be much greater than his image on the eye. It must be admitted, however, that we are frequently much deceived in the size and distance of objects when there are no other known objects near them by which to form a comparison.

Frederick. — What you have told us about judging of the size of objects by comparison, puts me in mind of the curious deception we witnessed at the exhibition of the Fantoccini the other evening. When the exhibitor himself came on the stage, I thought he was an immense giant; for after looking a length of time at the small figures, and the scenery painted to correspond with them, he seemed, in comparison, to be prodigiously large.

Mr. P. — It is a very good illustration of the subject, Frederick. Similar deceptions may be produced at any time by contrasts different from

those we have been accustomed to see; and in the dusk of the evening, when our principal guidance as to the size of objects depends upon the angle at which they are seen, we frequently mistake smaller and nearer things for larger and more distant objects. — The art of perspective depends upon the application of the principle that objects diminish in apparent size as they are more remote. The size of objects represented in a painting is drawn in proportion to the distances at which they are supposed to be placed; and the effect is materially aided by the colouring and shading, which, for distant objects, is made faint and indistinct, increasing in brightness as the objects approach the foreground, until, in some cases, they appear to stand out of the canvass.

Harriet. — Is the slow motion of carriages at a distance owing to their being seen so small?

Mr. P. — Yes, my dear, it is; for the length of the road is diminished by distance as well as the size of the carriage; so that the space of a mile, in a road seen far off, may be comprised within the diameter of a common ring, held at six inches from the eye. A carriage moving along a road, viewed from such a distance, at the rate of twelve miles an hour, would not cross the diameter of the ring in less than five minutes, and you would scarcely be able to see that it was in motion; but if the carriage were to pass within twenty yards at the same speed, whilst you were looking through the ring, it would cross the

diameter in a second of time, and appear to be moving with great velocity. The motions of the earth and of the planets are not visible to the naked eye in consequence of the great distance of the heavenly bodies. On looking at the moon, however, with a powerful telescope, the motion of the earth round its axis is very perceptible, for the moon is then seen moving off the field of view as the earth turns round.

HARRIET. — I wish you would let us look through your telescope, that we might see it, papa; for I should like very much to see the world really turning round.

MR. P. — Yes, my dear, you shall this evening, if the atmosphere be sufficiently clear.

FREDERICK. — Can you tell me, father, what it is that makes a lighted stick, when moved about quickly in the dark, appear as a line of light?

MR. P. — It is occasioned by the property which the retina possesses of retaining the impressions of objects a short time after the objects are removed. Impressions remain on the retina about the sixth part of a second: therefore, the removal of any object that returns to the same point within that time is not perceived, as the impression is renewed before the absence of the object has been discovered; and its track, during the sixth part of a second, appears as a line of light. An ingenious toy has been constructed to illustrate this effect of the duration of impressions on the retina. A drawing is made on each side

of a card — a bird on one side, and a cage on the other, for instance — and, by turning the card quickly round, both figures appear together, and the bird is seen in the cage. This toy is capable of producing many pleasing and ludicrous effects.

FREDERICK. — How very curious it must be! I will try to make one of them; and that the subject may have some connection with its cause, I will draw, on one side a blind man, and on the other side a pair of eyes, which will start into his head as the card turns round, and out of his head when it stops.

HARRIET. — And, to make the change still more extraordinary, let the poor man be bald and be without coat or shoes; and, on the other side, paint a fine curly wig, and a blue coat, and a pair of shoes, that will exactly fit him when he turns round to put them on.

MR. P. — If you execute as well as you design, the effect will be curious enough.

ROBERT. — You have not told us, father, what is the use of two eyes, and how it is that with two eyes we do not see double.

MR. P. — The use of two eyes is to increase the light; for, with one, objects appear only half as bright as when seen with two. Single vision with two eyes is produced by the axes of them being turned to the same object, and thereby occasioning the same impressions to be excited on both retinas. These impressions are conveyed by the optic nerves to the brain, to produce the sense

of sight in the mind. Persons who squint must see different objects with each eye, though they acquire the habit of attending only to one at a time; and those animals which have their eyes placed in opposite parts of their heads, must also receive different impressions from each eye.

HARRIET. — Does the coloured part of the eye let any light through to the screen at the back?

MR. P. — No; the rays are admitted only through that dark spot, in the centre of the eye, called the *pupil*.

HARRIET. — That part is much larger in the cat's eye than it is in ours, and becomes larger and smaller as she likes: what is the reason of that, papa? Can she see more than we can?

MR. P. — No, my dear, she cannot see any more objects; but we may suppose that to her they appear brighter than they do to us, as she can admit so many more rays of light when the pupils of her eyes are distended than can be admitted into ours.

HARRIET. — Sometimes the black part of her eye appears not thicker than a hair, and at other times it is quite round.

MR. P. — When the light is very powerful, the cat contracts her eye, so as to admit but a small quantity; and when the light decreases, she enlarges her pupil, and is enabled to admit perhaps ten times more light than can enter our eyes. She is thus able to see objects when there is not light sufficient for us to distinguish them.

HARRIET. — Then it is true that cats can see in the dark! I wish the pupils of our eyes would open and close in the same way.

MR. P. — They do open and close, Harriet, though not to such an extent as those of the cat. When we are in a strong light the pupil contracts, because too much light occasions pain to the delicate nerves of the eye. As the light decreases, the pupil expands, and you may notice a very perceptible difference in the size of the pupils when exposed to a bright light and when coming out of a dark room. Look, Harriet, at Robert's eyes, now that he is in the glare of the sun, and we will get him to go into the dark closet for a few minutes, that you may see whether any change will take place in the size of the pupils.

HARRIET. — The black spot seems very small at present. — Now, Robert, go into the dark, and let us see if you have got cat's eyes when you come back?

(ROBERT *goes into the closet, and when he has been shut up there a short time, Mr.* POWELL *tells him to come back again.* HARRIET *pulls him towards the window, into which the sun is shining, to look at his eyes, when* ROBERT *covers them with his hands, and utters an exclamation of pain.*)

HARRIET. — Do not hold your hands to your eyes, Robert, I cannot see them.

ROBERT. — The light hurts them so, that I can scarcely bear it. (ROBERT *retires a little dis-*

tance from the window, and then withdraws his hands from his face.)

HARRIET. — Yes, now I see; the black part has, indeed, spread itself out to twice the size it was before you went into the dark. But what made you cry out, Robert? Cats do not scream when they swell their eyes, ha, ha!

ROBERT. — I do not know how cats manage, but I know, Harriet, you would have called out if your eyes pained you as mine did me.

MR. P. — The pupils of Robert's eyes having enlarged themselves in the dark, admitted more rays when he returned to the light than the retina could bear without pain, because the human eye has not the power of immediately contracting itself like that of the cat. If cats could not contract the pupils of their eyes more rapidly than we can, they would suffer intense pain on coming from the dark, with their pupils fully enlarged, into the light of the sun.

FREDERICK. — I have observed that when I go out of doors at night, from a lighted room, I cannot see any thing at first, though, after I have been out a short time, I can see tolerably well; I suppose this is owing to the pupil of the eye being small at first, and afterwards enlarging and admitting more rays.

MR. P. — It is so, my dear; and you may therefore conceive that if the pupils of your eyes were capable of being more enlarged, you would see objects on a dark night still more distinctly.

You may also understand, from that circumstance, how it would be possible for eyes more sensitive than ours to see objects when all is perfect darkness to us, as I mentioned to you in our Conversation on Light.*

* Page 130.

CONVERSATION XXI.

MAGNIFYING GLASSES.

ROBERT. — You said, father, the other morning, that the power of magnifying glasses depended upon the refraction of light: I wish you would explain how refraction can make things seem larger than they are.

MR. P. — The effect of magnifying glasses, or convex lenses, as they are generally termed, is produced by their being so formed as to converge the rays of light, by refraction, on passing through the glass. You must not suppose, however, that objects viewed through such a glass appear larger than they are; the apparent increase in their size is owing to our being able to look at them nearer through a convex lens than we can do with the naked eye.

ROBERT. — Surely, father, you do not mean to say that a fly is really as large as it seems to be when I am looking at it through a good magnifying glass?

MR. P. — The same object appears large or small according to the distance at which it is seen,

as I explained to you in our Conversation on Vision, and a small object seen near appears larger than one many times its size at a distance. Thus, an object the length of an inch, at a foot distant from the eye, will appear as large — that is, it will conceal from view — an object one hundred times its size placed at a distance of one hundred feet; and the shadow of a pea, when held near the eye, will thus cover the face of the full moon. When a distant object — the figure of a man for instance — approaches us, it is increasing in apparent magnitude every step the man advances; and when he comes within one foot, his face appears, probably, several hundred times larger than it did when first seen. Yet we do not say, in this case, that his face is magnified, because, as our eyes can see objects when only five or six inches distant, every thing we are accustomed to look at within that distance appears to be only of what we call its *natural size.* Now, when, by means of a lens, we are enabled to look at objects more closely than we can with the naked eye — suppose at three inches instead of six — the apparent increase of size we consider unnatural, and we say the objects are *magnified.* To a person who is very short-sighted, and accustomed to view objects as near as three inches, an object seen at that distance he would consider only of its natural size.

ROBERT. — Then how can we tell what is the real natural size of things?

MR. P. — The meaning of the term "natural

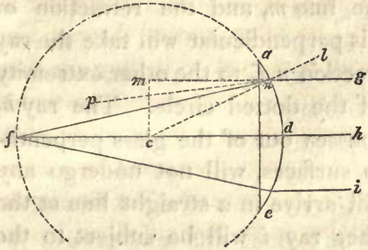
size" is merely, that objects seen at a certain distance appear of the same size as we have been accustomed to see such objects at such a distance. To a fly, we must suppose, that objects appear as large as they do to us when viewed through our most powerful magnifiers, yet to it they are then only of their natural size. If we were accustomed to view all things as closely as a fly must do, they would appear to be equally increased in size as when viewed through a microscope, yet we should not then consider them to be magnified, any more than we now think a man is magnified by coming nearer to us.

FREDERICK. — How is it, father, that a magnifying glass enables us to look at things so closely?

MR. P. — It is by making the diverging rays issuing from a near object parallel, by their refraction, on passing through it. The image of the object is thereby formed distinctly on the retina at the back of the eye, which it cannot be when the rays diverge much on entering it. I will, however, explain the manner in which the rays of light are refracted, on entering and on passing out of a lens, to produce this effect. The kind of lenses usually employed are *double convex lenses;* that is, glasses rounded out on each side, like two watch-glasses joined together: but the explanation will be more clear if we consider, at first, the refraction in glasses that are rounded on one side only and flat on the other. These glasses are called *plano-convex* lenses.

HARRIET. — Then those must be the shape of a single watch-glass, laid flat upon the table.

MR. P. — Exactly so. Suppose *a e* to be such a glass, seen edgewise; the rounded part of which, *a d e*, forms a portion of the dotted circle whose centre is *c*. The lines *g h i* represent parallel rays of light falling upon the convex surface of the glass. On entering the glass these rays will be refracted nearer to the perpendicular of the surface, as before explained to you.* The line drawn from the centre of a circle to its circumference is, as you are aware, perpendicular to that point through which it is drawn; therefore the line *c l* will be perpendicular to the surface of the glass at the point where the ray *g* enters.



FREDERICK. — I see you have made the ray *g* go through the glass to *m* in the same direction in which it enters; but, of course, it must be refracted towards the perpendicular.

MR. P. — Yes, just so. The dotted line is continued merely to show the amount of the refraction, for as soon as the ray enters the glass it is bent one-third nearer to the perpendicular, in the direction *n p*. On coming out of the glass

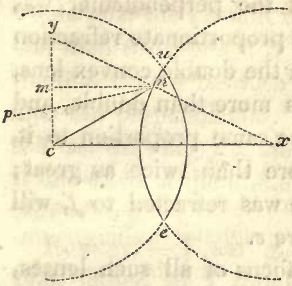
* Conversation XVI. p. 136.

into the air, it is again refracted, and in the same degree, *from* the perpendicular of the surface from which it issues. The perpendicular to this second surface, *a e*, is the line *m*, and the refraction of one-third from this perpendicular will take the ray of light in the direction *n f*, to the other extremity of the diameter of the dotted circle. The ray *h*, as it enters and passes out of the glass perpendicularly to its two surfaces, will not undergo any refraction, and will arrive in a straight line at the point *f*. The other ray *i* will be subject to the same refraction as the ray *g* was, and will, in a similar manner, be refracted to *f*, where the three rays will meet. Any other parallel ray entering the glass will, by undergoing the same refraction, arrive at *f*, where all the rays will concentrate in a point, and that point is called the *focus*, as all the rays of light and heat from the sun are centred there in a burning glass.

Frederick. — Then the focus of such a glass will be just the length of the diameter of the circle that forms the convex side?

Mr. P. — Yes, Frederick, that is the case when the refracting power of the medium is one third, as in common glass; but when the refraction is greater than one third, the rays will come to a point nearer the lens, and the contrary when the refractive power is less. In a double convex lens made of glass the focus will be in the *centre* of the circle, as I will now show you. Let *n p* be the direction in which a ray of light will be re-

fracted on entering the first convex surface of the lens *u e*, as in the last figure. On coming out of the glass into the air, the ray will be refracted one-third from the perpendicular of the *convex surface*. The perpendicular to this surface, at the point *n*, is the line *x y*, drawn from the centre, *x*, of the circle that forms the second convex side of the lens. You see, therefore, that the directions of the ray of light, and of the perpendicular from which it is to be refracted, differ much more than they did in the other lens; in which the direction of the perpendicular from its *flat* surface was *n m*.



As the degree of refraction is in proportion to the difference between the direction of the ray and that of the perpendicular, you must see that the more these differ the more will the ray be bent from its former course.

Harriet. — I thought the degree of refraction had been always the same.

Mr. P. — It always bears the same *proportion* to the perpendicular of the refracting surface, but the greater the difference between that perpendicular and the direction of the incident ray, the greater will be the amount of that proportion; in the same way that the third of nine inches is greater than the third of three. For instance, in

the single convex lens the difference between the direction of the ray and the perpendicular was only from *m* to *p*, and the proportionate refraction brought the ray to *f*. In the double convex lens, however, the difference is more than double, and the refraction, to bear the same proportion to it, must consequently be more than twice as great; and the ray, that before was refracted to *f*, will be bent towards the centre *c*.

Frederick. — Is the focus of all such lenses, then, in the centre of the circle?

Mr. P. — Yes, after allowing for the thickness of the glass, which, in some lenses, bears a considerable proportion to their focal distance. I have been thus particular in tracing the refractions of the rays of light through a lens till they are brought to a focus, as this is seldom attempted to be explained in a manner intelligible to young persons. I hope I have succeeded in making you understand the subject, but the most satisfactory mode of impressing it upon your minds is, for you to make a drawing of each kind of lens, on a scale large enough to enable you to measure the degrees of refraction accurately.

Robert. — I will make such a drawing this afternoon, and then I shall see whether all the parallel rays will be refracted by the same rule into the centre.

Mr. P. — You must bear in mind in your drawing, that the degree of the refraction, both

to and from the perpendicular, is one-third of the whole *after* the amount of the refraction is added; and that, therefore, it is one-half of the length of the line drawn between the direction of the ray and the perpendicular. Thus, you perceive, in the last drawing, *p c*, the amount of the refraction, is one-third of the whole line *c y*, but it is also the half of *p y*.

ROBERT. — I am glad you have mentioned that, father, or I should have made a mistake, and have added only one-third the difference between the ray and the perpendicular.

CONVERSATION XXII.

IMAGES OF OBJECTS.

Mr. P. — Well, Robert, did you make your drawing last night, and were you satisfied that all parallel rays are brought to a focus at the same point?

Robert. — Yes; I found that the parallel rays entering near the edge of the glass are refracted more than those near the middle, owing to their being farther from the perpendiculars of the two convex surfaces, which makes up for the difference in their distances from the centre. It was that which puzzled me at first.

Mr. P. — Having now traced the rays of light to a focus, I will proceed to explain some of the phenomena which this concentration of the rays of light produce. The burning-glass is the most obvious illustration of this effect of convex lenses.

Harriet. — Are burning glasses nothing but glasses rounded out on each side, papa?

Mr. P. — They are nothing but convex lenses, in which all the light from the sun that falls upon

their surfaces are brought to a point, by refraction, in the manner I have described, and form in the focus a small image of the sun. As most of the light and heat spread over the surface of the burning glass are concentrated in that small round spot, that spot must contain nearly the same quantity of light and heat that were before diffused over the glass, and its intensity is proportionably increased. The quantity of heat from the sun is the same, but the intensity of it, on one point, is increased by taking heat from other parts. Thus, the space round the bright image is always dark, in consequence of the rays of light, that would otherwise have fallen there, being directed to the focus of the lens.

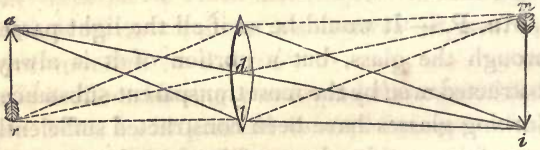
Frederick. — Then, I suppose, when the surface of the glass is one hundred times larger than the bright spot, the heat on that point would be one hundred times greater than the common heat of the sun.

Mr. P. — It would be so if all the light passed through the glass, but a portion of it is always obstructed even by the most transparent substances. Burning glasses have been constructed sufficiently powerful to melt plates of iron, and to convert slates into glass, in a few minutes. Such glasses, however, scarcely act upon transparent bodies, and the sun's rays may be concentrated by them on a glass of clear water without any effect, as the rays pass through it; but, if the water be discoloured, it

will speedily boil. The reflected rays of light, proceeding from all objects, are concentrated in the same manner as the direct rays from the sun; as I have shown you frequently in our conversations on vision, by making all the objects outside the window visible by collecting their rays in the focus of a convex lens; and I will now repeat the experiment. (*Mr.* POWELL *holds a convex lens between a white screen and the window, at its focal distance from the screen, so as to form a distinct inverted image of the objects in the road.*)

ROBERT.—But the rays of light are not brought to a point now, as they are by a burning glass, and the picture on the screen is larger than the glass itself.

MR. P. — I will endeavour to explain why the image should appear larger than the glass, though the rays of light are brought to the focus. Suppose the lines *a c*, *a d*, *a l* to represent rays of light



proceeding from the point of the arrow *a r*, and falling upon the surface of the double convex lens *c d l*.

HARRIET. — Are the rays of light from so small a thing as the point of an arrow spread all over the surface of the glass.

Mr. P. — Yes, my dear, every point of an object, as I have previously informed you, sends out rays of light, and we could not see the whole of an arrow unless rays proceeded from every part of it to the eye. The rays from the point of the arrow, therefore, in passing through the glass, are refracted in the directions *c i*, *d i*, and *l i*, forming at *i* — where we will suppose them to be brought to a focus — the image of the point *a*. I have here only drawn three of the rays from the point *a*, to avoid confusion; but you must understand that rays proceed from the same point to all parts of the surface of the glass, and are reflected to *i*, where they contribute to form the image. In the same manner, the rays from the other end of the arrow are concentrated at *m*, and those from all the intermediate parts are brought to their several points between *m* and *i*, forming there a complete inverted image of the arrow.

Frederick. — So that all the separate rays are brought to separate points; and, as the different rays come to the glass in different directions, they are brought to points in different parts of the screen.

Mr. P. — Exactly so.

Harriet. — But what makes the houses, and trees, and men appear to be upside down?

Mr. P. — You observe, in the figure, that the central rays of every pencil of rays, from the top and bottom of the arrow, proceed in straight lines through the centre of the glass, and continue in

the same direction in passing out of it. Thus, the rays *a d* and *r d* cross one another in the middle of the lens, and the ray from the top of the arrow proceeds to *i*, and that from the bottom to *m*; and as all the other rays converge round the central ones, the image must be inverted. You may convince yourself that the image would be formed in this manner by accurately measuring the refractions of the different pencils of rays in a drawing on a large scale, such as Robert made yesterday.

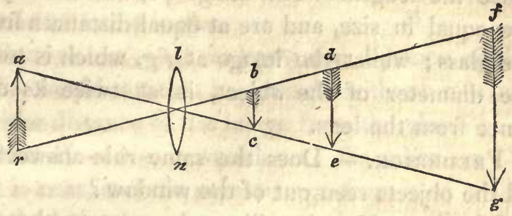
ROBERT. — I see you have made the image larger than the object, — how can that be, father?

MR. P. — The size of the image depends upon the distance at which it is formed from the lens. I will show you that this is the case by first using the same lens I have just employed, and then substituting one of a longer focus. (*Mr.* POWELL *forms images of the objects outside the window upon the screen with the two lenses, as described.*)

HARRIET. — Every thing appears much larger with the second glass, but not so bright, nor so distinct, as before; — what makes the difference, papa?

MR. P. — This figure will make the cause quite evident. The arrow, *a r*, is supposed to be sending out rays of light to the lens, *l n*. The central rays of each pencil will cross in the centre of the lens, as I have already stated, and, after passing through, will diverge towards *b c*. If the rays be brought to a focus at *b c*, a small image

will be formed there equal in length to the distance between the diverging lines proceeding from



the two extremities of the object. If the image be formed at twice the distance, as at *d e*, it will be twice the length; and, at four times the distance, it will be four times the length, as at *f g*. But, as the same quantity of light passes from the object through the lens in each case, it must be diffused, when the image is large, over a much greater surface; and, therefore, as the image increases in size, it diminishes in brightness.

FREDERICK. — The image at *d e* seems to be the same size as the object.

MR. P. — Yes, because it is at the same distance from the lens. I need not, perhaps, tell you, that when two straight lines cross one another, their opposite angles are equal, and that, at equal distances from the point at which they cross, the lines will be equally distant. As the rays from the top and the bottom of an object cross in the middle of the lens, the length of the image formed behind it will depend upon the distance from the lens at which it is formed. Thus

the object *a r*, in this figure, is twice as distant from the glass as the first image *b c*, and it is twice the length. The image *d e*, and the object are equal in size, and are at equal distances from the glass; whilst the image at *f g*, which is twice the diameter of the object, is at twice its distance from the lens.

FREDERICK. — Does the same rule answer for all the objects seen out of the window?

MR. P. — Yes, it will apply even to the sun himself; for the small image formed in the focus of a burning glass bears the same proportion to the size of the sun, as the distance of the focus from the glass bears to the distance of the glass from the sun.

HARRIET. — Then, if we could only get a screen large enough and far enough off, and a glass of proper focus, we might make the sun's image as large as himself.

FREDERICK. — And, even on a small scale, we might, I suppose, if we knew the distance of the sun, measure his size by measuring the image and its distance from the glass.

MR. P. — Yes, Frederick; or by knowing the size of the sun, you might, in the same manner, estimate his distance from the earth. Measurements might be taken, in this way, of inaccessible heights, or of other objects, by first ascertaining their exact distance, and then measuring the size of their images and the focal length of the lens. For instance, if the image of a tree, 400 yards off,

were formed at a distance of one yard from a lens, and measured exactly one inch, then we should know that the height of the tree was 400 inches, that is 33 feet 4 inches.

FREDERICK. — If we know the distance of the focus, would not that be enough, without measuring the distance of the image from the glass?

MR. P. — No, it would not; for when an object is near, and the rays diverge from it on entering the lens, they are not brought to a focus so soon; and the nearer the object is brought to the lens, the more distant and the larger will be its image. When the object arrives at the focal distance, the rays from it will be so divergent, that on passing through the lens they will be rendered parallel, and not form any image. If the object be brought still nearer, the rays will continue to diverge on passing through the glass, but their divergence will not be so great as it was before.

HARRIET. — I do not yet understand, papa, why we are able to look at things nearer with magnifying glasses.

MR. P. — I have just now mentioned that, as parallel rays are converged to a focus on passing through a convex lens, so, on the contrary, rays of light diverging from the focus to the lens, are made parallel by their refraction on passing through the glass; therefore an object placed in the focus of such a lens may be seen distinctly through it by the eye, however near the focus of

the glass may be. If, then, a person who cannot see an object clearly when placed nearer to his eye than eight inches, is able, by a convex lens of one inch focus, to see the same object eight times nearer than before, it will be magnified eight times in diameter. If, again, he use a lens whose focal distance is not more than the twentieth part of an inch, it will make objects appear to be 160 times longer, and their surface 25,600 times larger.

HARRIET.—And will it magnify so many times merely by your being able to look at things so much nearer?

MR. P.—Yes, my dear, that is the only way by which the astonishing effects of magnifying glasses are produced; for the nearer you can view an object, the larger it will appear, as I mentioned in our conversation on vision.

CONVERSATION XXIII.

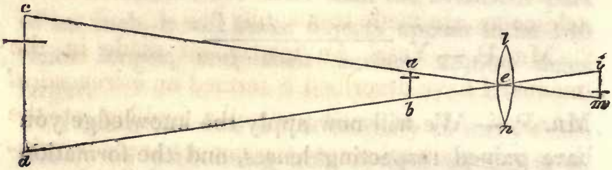
OPTICAL INSTRUMENTS.

Mr. P. — We will now apply the knowledge you have gained respecting lenses, and the formation of the images of objects by them, to explain the cause of the magnifying powers of telescopes and other optical instruments.

Harriet. — I have often wondered, papa, when looking through your telescope, how distant things could be brought so near as to make me think I could almost touch them; and I shall be quite glad to know how it is.

Mr. P. — Refracting telescopes, which are those most commonly used, consist of a convex lens placed at the large end of the tube, and called the *object glass*. The focus of this glass is generally nearly as long as the tube. Its use is to form an image of the objects looked at, and the longer the focus the larger the image will be, as I mentioned to you yesterday. Suppose an object thirty feet high were seen at a distance of 360 yards, and the image of it were brought to a focus three feet from the object glass, such an image

would be 360 times less than the object; that is, one inch long. This image, viewed at a distance of one yard, would appear the same size as the object does when viewed by the eye from the end of the telescope, as will appear from this figure. Suppose *c d* to be the object, *l n* the lens, and *i m*



the image. I will now draw *a b* at the same distance before the lens as the image is behind it, and (because it is drawn between the converging rays from the two extremes of the object, which cross each other at *e*,) it will be also of the same size as the image. It is evident, therefore, that to an eye situated at the point *e*, *a b* will just cover the object, and will appear as large to the eye.

Harriet. — But if the object glass make a thing appear only of the same size as when looked at by the eye, what good does it do?

Mr. P. — You forget, Harriet, that we have as yet supposed the image to be viewed not nearer than at the distance of one yard, that is, thirty-six inches, from the eye; but most persons would be able to look at it six times nearer than that, and it would then appear to be six times longer than when seen by the naked eye. Again, by using a

second convex lens, called an *eye-glass*, of one inch focus, we can look at the image when only one inch from the eye, and it would then appear thirty-six times larger in diameter than the object, and thirty-six times thirty-six, that is 1296, times larger in surface.

FREDERICK. — Is it in this manner, then, that telescopes are made to magnify?

MR. P. — Yes. An instrument made in the manner I have described is termed an *astronomical telescope.* It is used only for looking at the heavenly bodies, because the images are shown inverted. To make the objects appear upright two other eye-glasses are used, of the same focus, in which the rays of light are made to cross one another, and the object is thus seen in its natural position. The most powerful telescopes are the reflecting ones, in which the image of the object is formed by reflection from a concave mirror, and it is afterwards viewed by an eye-glass of small focal length. All telescopes, however, depend upon the principle of first forming an image of the object looked at, and then viewing that image by a lens of small focus; and the larger the image, and the nearer it can be looked at, the greater will be the magnifying power.

FREDERICK. — Then by forming a very large image, and using a very small eye-glass, a telescope might be made to magnify to any size, I suppose?

MR. P. — Many practical difficulties arise in

the construction of telescopes that limit their magnifying power. For instance, as you increase the size of the image, the quantity of light upon it is diminished, as I have before mentioned; and, therefore, the diameter of the tube and the circumference of the object glass, or reflector, must be large in proportion, or the image would be too dim to be clearly seen. You will have some idea of the difficulties attending the construction of large telescopes, when I tell you that the tube of the large reflecting telescope made by Dr. Herschel weighed many thousand pounds, and that the reflector itself weighed nearly one ton. The diameter of its tube was four feet ten inches, and its length forty feet: this telescope magnified about 6000 times.

Robert. — But could not he have made a shorter telescope magnify as much by using an eye-glass with a very short focus?

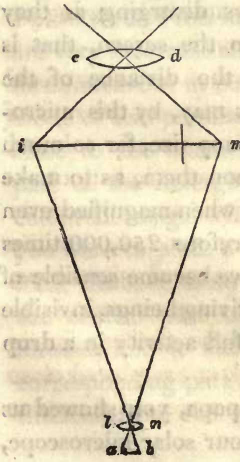
Mr. P. — When eye-glasses of very short focal length are used, the great refraction of the rays of light separates them into their prismatic colours, and makes the images seem very indistinct. — Having now told you how objects are apparently brought nearer by telescopes, you will readily understand the effect of the compound microscope, which magnifies objects in the same manner.

Robert. — How can that be, father, for in microscopes the things we look at are placed close to the glass, and with telescopes we see things at a great distance?

Mr. P. — The only difference between them is, that in telescopes, as the rays of light proceed from distant objects nearly parallel, the image is formed in the focus of the object glass; and, in microscopes, the image is formed beyond the focus.

Harriet. — How is that, papa?

Mr. P. — The object glass in a microscope is of very small focal length, and the object to be viewed is placed nearly in its focus; therefore the rays diverge so much on entering the glass, that it cannot concentrate them into points until they have passed far beyond the focus of parallel rays. The image is, consequently, as much larger than the object as its distance from the glass is greater, as I stated to you yesterday; but this sketch will, perhaps, impress the subject more upon your minds. The small object, *a b*, is placed so near



the focus of the small lens, *l n*, that the rays from it are not brought to a focus until they have arrived at *i m*. As the rays from the two extremities of the object cross each other in the centre of the object glass, *l n*, the size of the image must depend upon its distance from the lens; and at *i m* — which is ten times as far from the lens as *a* — it will be ten times longer than the object. This

image, when viewed by the naked eye, will appear, therefore, ten times the length of the object; and when looked at through an eye-glass, *c d*, that will enable you to see it ten times nearer, it will appear to be ten times ten, or one hundred times, the length.

Frederick. — Does the solar microscope magnify objects in the same way?

Mr. P. — Not exactly. In the compound microscope an enlarged image of the object is formed, and it is then viewed by an eye-glass; but, in the solar microscope, we look at the image itself, thrown on a screen. The light of the sun is first reflected by a mirror, on the outside the window-shutter, upon a lens that concentrates the light upon the object to be viewed, which is placed near the focus of a smaller lens, as in a compound microscope; and the cross rays diverging as they proceed, form an image on the screen, that is magnified in proportion to the distance of the screen from the lens. Objects may, by this microscope, be magnified to almost any size, for so much light may be concentrated upon them, as to make their images distinctly visible when magnified even 500 times in length, and therefore 250,000 times in surface. In this manner we become sensible of the existence of hundreds of living beings, invisible to the naked eye, moving in full activity in a drop of water as their little world.

Harriet. — I remember, papa, you showed us some mites in cheese with your solar microscope,

last summer, which appeared as large as crabs, crawling about the screen with crumbs of cheese in their mouths that seemed large enough for a man's dinner.

Mr. P. — The astonishing effects of the magic lantern are produced in nearly a similar way to those of the solar microscope, the light of a lamp being employed as a substitute for that of the sun.

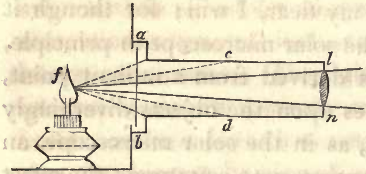
Frederick. — I wish you would describe it to us, father.

Mr. P. — Yes, my dear, I will; for though it closely resembles the solar microscope in principle, yet, as the light is derived from a radiant point, and therefore strikes upon the objects divergingly instead of parallel, as in the solar microscope, an additional lens is necessary to counteract the effect of this divergency. Many of the descriptions that I have seen of this instrument in elementary works, are very incorrect and unsatisfactory; I will therefore endeavour to make you clearly understand the mode of its operation. If you hold a painted slide close to the flame of a candle, it will intercept part of the diverging rays, and a large indistinct coloured image will be thrown on the wall. If you were to place a convex lens a little beyond its focal distance from the slide, a distinct image of the central part of the painted figure will be formed, and it will be as much larger than the corresponding part of the object as the distance of the lens from the wall is greater than its distance

from the object. This is a magic lantern in its simplest form.

Robert.— What should prevent the whole of the figure from being seen, as in the real magic lantern?

Mr. P.— It is the divergence of the rays as they proceed from the candle; but I can best explain this by a drawing. Here *a b* represents the position of the painted slide in the magic lantern, *c d* the tube through which the light proceeds to the screen, and *f* the flame of the lamp, sending forth its diverging rays to the painted figures.



You perceive that most of the rays, excepting those that pass through the central part, are obstructed by the tube, and that only the middle ones reach the lens, *l n*; the images of those parts, therefore, would be alone converged to a focus on the screen in such a magic lantern.

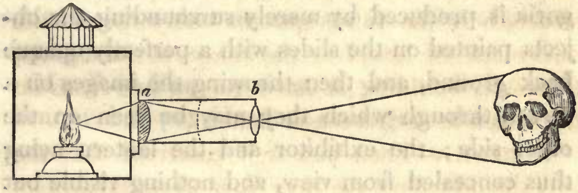
Robert.— Then how is it contrived that the lens should collect the rays from all parts?

Mr. P.— A large and powerful convex lens is placed close to the object, by which the rays of light are greatly concentrated, so as to cause most of the rays from the figure to fall upon the second lens at the end of the tube.

Frederick.— Then the second lens acts in

the same way as the object-glass in a solar and in a compound microscope.

Mr. P. — Yes, my dear, it does. It is placed a little beyond its focal distance from the object, so that each pencil of diverging rays flowing from different parts of the object may be brought to a point considerably beyond the real focus of the lens, and if a screen be placed at a proper distance, a distinct image of the painted figure will be seen. As the rays of light cross one another in the middle of the object lens, the image will increase in size in proportion to the distance of the lantern from the screen, but as it increases in size its brightness diminishes, because the same quantity of light is then spread over a larger surface.—Here is a section of a complete magic lantern, showing the situations of the lenses, *a* and *b*, and the direc-



tion of the rays of light, from their first divergence to the painted glass, till they cross in the object-lens, and again diverge to the screen.

Frederick. — Then the magnifying effect of the magic lantern is owing only to the rays of light from the lamp being collected to a focus on the screen after passing through the painted glass?

Mr. P. — That is all. When the lantern is removed farther from the screen, the image will become indistinct, and to bring the rays to a focus it will be requisite to move the object lens nearer to the painted slide, to increase the divergence of the rays, and thereby prevent them from concentrating until they arrive at the more distant screen. When the lantern approaches the screen, on the contrary, it will be necessary to diminish the divergence of the rays by removing the lens farther from the object. As the rays from the object cross in the centre of the lens, of course the images are inverted, but this is easily remedied by inverting the painted figures, which are then shown upright.

Frederick. — What is the difference between the magic lantern and *phantasmagoria?*

Mr. P. — The exhibition called phantasmagoria is produced by merely surrounding the objects painted on the slides with a perfectly opaque back ground, and then throwing the images on a screen through which they may be seen on the other side; the exhibitor and the lantern being thus concealed from view, and nothing visible but the luminous figures. As the lantern recedes from the screen the objects enlarge, and seem to advance upon the spectator; and as the exhibitor brings the lantern nearer, they seem to depart. The effect is still more wonderful if the image be thrown upon smoke, rising from a concealed fire; in which case the moving smoke appears to give

motion to the figure, and, to a person not aware of the deception, it produces an appalling sensation. The image may also be reflected from a thick fog, as from a screen. Many a ghost story owes its origin to deceptions of this kind.

Harriet. — Even when I know what it is, I cannot help feeling afraid when you exhibit some of the horrible figures in the magic lantern.

Mr. P. — It is very foolish of you, Harriet; you should endeavour to conquer such weakness; and to give you an opportunity of doing so, I will exhibit the magic lantern this evening: it will be an agreeable termination to the subjects of light, lenses, vision, and optical instruments.

Harriet. — Oh do, dear papa! I shall be so much pleased if you will.

Robert. — And if you will let me, father, I will paint round the figures on some of the slides with black, so that we may see the effect of phantasmagoria.

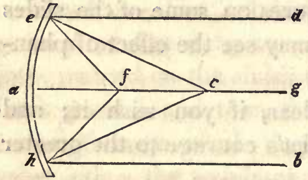
Mr. P. — Yes, my dear, if you wish it; and then we shall put Harriet's courage to the greater test.

CONVERSATION XXIV.

CONCAVE AND CONVEX MIRRORS.

FREDERICK. — Are the figures we see in the air before a concave mirror produced by reflection, in the same way as the images behind a looking glass?

MR. P. — Yes they are. The effect is very extraordinary, and I will endeavour to explain the the cause of it. Suppose *e h*, to be a concave mirror, forming part of the interior of a globe, the centre of which is *c*. Now all lines that are drawn from the centre of a circle to its circumference are perpendicular to that point of the circumference to which they are drawn. The surface of a concave mirror may, therefore, be considered as composed of innumerable small plane mirrors, so arranged that lines of equal length drawn from the centre of a circle will fall perpendicularly upon them. If, then, rays of light issue from the centre *c*, and fall upon the concave



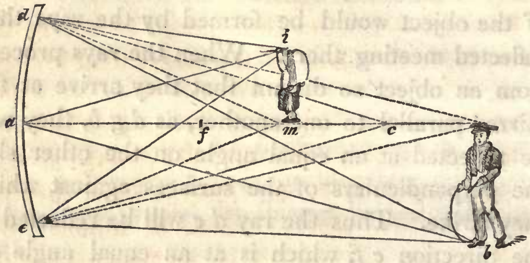
surface of the mirror *e h*, all the rays will be reflected back upon the same point.

FREDERICK. — Just in the same way that rays striking perpendicularly against a looking-glass are sent back to the object?

MR. P. — Yes; and at the centre, *c*, an image of the object would be formed by the rays thus reflected meeting there. When the rays proceed from an object so distant that they arrive at the mirror parallel to one another, as *d g b*, they will be reflected at an equal angle on the other side the perpendiculars of the surfaces against which they strike. Thus the ray *d e* will be reflected in the direction *e f*, which is at an equal angle on the other side of the perpendicular, *c e*. The ray *b h* will be also reflected to *f*; and all the other rays will, in the same manner, be concentrated at that point; which is, therefore, termed the focus of such a mirror. The focus of parallel rays is half way between the centre of concavity and the mirror. At that point the image of a distant object will be formed, and may be seen in an inverted position in the air. If you stand before this concave mirror beyond the centre of its concavity, you will see yourselves in the air. (*Mr.* POWELL *places a concave mirror on the table into which the children look; and they express great astonishment at seeing themselves in the air with their feet uppermost.*)

HARRIET. — What makes us appear to be upside down, papa?

Mr. P. — I have hitherto considered the object to be a luminous *point* placed in the axis of the glass; that is, in a line, *c a*, drawn through the middle of it to the centre of concavity, *c*. But let us now trace the reflection of the rays from an



object placed below the axis. We have here a representation of Robert standing before the concave mirror, and below its axis. Rays of light must proceed from his body in all directions to the mirror, but we will only follow three of those proceeding from his head and his feet, and as all the other rays, when converged to a point collect round their central ones, we will first trace the reflection of the ray *b a*, as the other rays from the same point will collect on the line of its reflection. The ray *b a*, therefore, striking against the the point *a*, to which the axis, *c a*, is perpendicular, will be reflected at an equal angle on the other side; that is, above the axis, in the direction *a i*. The rays *b e* and *b d* will be reflected in the same way, and meet on the line *a i*, at *i*, where an image of Robert's feet will be formed. The rays

proceeding from his head, by obeying the same law of reflection, will be brought to a point on the axis of the mirror at *m*, and all the intermediate rays from his body will be reflected in their proper positions between *m* and *i*, forming there an inverted image of his whole figure.

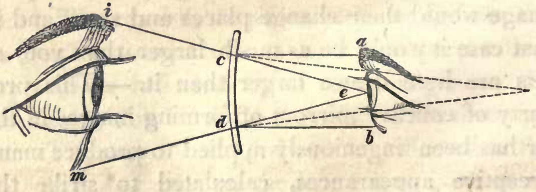
Robert. — But my little image is not in the focus, for it is nearer to the centre than it ought to be.

Mr. P. — Your figure is represented as being so near the mirror, that the rays diverge as they proceed to it. Rays that diverge when they fall upon a concave mirror, cannot be brought to a point so soon as parallel rays, and the greater the divergence the more distant will the image be from the focus, as is the case with images formed by convex lenses. Thus, if the object be placed at the centre of concavity, the image will be formed there also, and their sizes will be equal. If the object be placed still nearer, the image will recede farther from the glass, and be larger than the object. For instance, if you were placed as near to a large concave mirror as your image is represented to be in the drawing, you and your image would then change places and sizes, and in that case it would be as much larger than you, as you are here drawn larger than it. — This property of concave mirrors of forming images in the air has been ingeniously applied to produce many deceptive appearances, calculated to strike the uninitiated with the greatest astonishment, and that

have been regarded by the ignorant as the effects of magic.

ROBERT. — When I look nearer to the concave mirror, I see my face behind it, and very much magnified.

MR. P.—Yes, Robert, that is another peculiarity of concave mirrors. When an object is placed in the focus of such a mirror, the incident rays diverge so much that they are reflected from it parallel to one another, and no image is formed. If the object be brought nearer than the focus, the rays *diverge* after they are reflected, though not so much as before. Now, persons cannot usually see any object distinctly if placed nearer to the eye than six inches, owing to the great divergence of the rays from a near object; but as a concave mirror reflects the rays in a less diverging direction than they were when they fell upon it, the image reflected can be looked at nearer than the object can with the naked eye; and the nearer you can look at any thing, the larger it appears, as I have previously explained.* The subject will be more intelligible, perhaps, by means of this drawing. Let *a b* represent Robert's

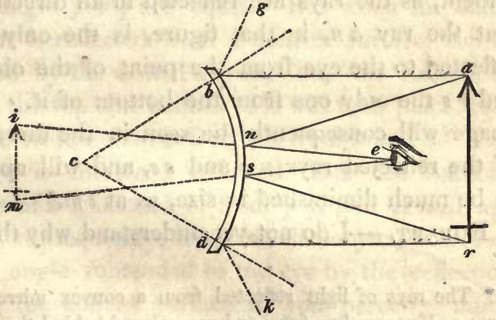


* Conversations on Vision and Magnifying Glasses.

eye looking at itself in the concave mirror, *c d*. The parallel rays, *a c* and *b d*, from the eye-brow and from the lower part of the eye, will be reflected into the pupil of the eye at *e*, and the image will be seen in the direction of the reflected rays *i e* and *m e*, viz., at *i m*, where the magnified image will be visible.

HARRIET. — What is the reason, papa, of every thing appearing so little in the round mirrors that we sometimes see in drawing-rooms?

MR. P. — They are called *convex mirrors*, and bulge outwards in the middle, instead of being hollowed, as concave mirrors are. The effects produced by reflection from their surfaces are, as you must have observed, totally different from those produced by reflection from a concave surface. Parallel rays of light, falling upon a convex mirror, are made to diverge, as if proceeding



from a point behind the mirror, as will appear from this figure. The parallel rays, *a b* and *r d*,

proceed from the object *a r* to the convex mirror *b d*, which has its centre of convexity at *c*; from which the surface of the convex mirror is drawn. Lines drawn from *c* to the points *b* and *d* will, therefore, be perpendicular to the surface of the mirror at those points, and the incident parallel rays will be reflected at an equal angle on the other side of them, that is, in the diverging directions *b g* and *d k*.

Frederick. — Then such rays will never meet at a focus?

Mr. P. — No; they will, on the contrary, diverge more and more the farther they extend.

Harriet. — How does the diverging of the rays make things appear less than they are?

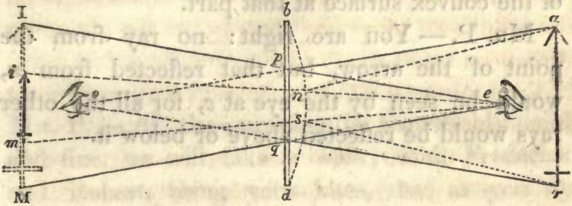
Mr. P. — I will show you how that effect is produced, by tracing the reflection of other rays from the object *a r*, to the eye placed at *e*. It is evident, as the rays are reflected in all directions, that the ray *a n*, in that figure, is the only one reflected to the eye from the point of the object, and *r s* the only one from the bottom of it. The image will consequently be seen in the direction of the reflected rays *n e* and *s e*, and will appear o be much diminished in size, as at *i m*.*

Robert. — I do not yet understand why things

* The rays of light reflected from a convex mirror, diverge as if proceeding from an image placed behind the glass, between the centre of convexity and the convex surface; but the apparent distance of reflected objects is generally far beyond the virtual focus of the mirror.

should appear less in a convex mirror than in a common looking-glass.

Mr. P. — It is owing to the convex surface reflecting the rays from points nearer to each other. Thus, suppose the straight line *b d* to be a plane mirror, the ray from the point *a* of the



object will be reflected, to the eye at *e*, from *p*, and the ray from *r* will be reflected from *q*, and the image will appear at I M of the same size as the object would appear if viewed from the other side the glass at *o*, because the angle *p e q* and the angle *p o q* are equal. But when the same object is reflected from a convex surface, represented by the dotted curved line, the reflections from the top and bottom of it will take place from points nearer than before, viz. from *n* and *s*. The image is therefore reflected from the reduced space of *n s*, instead of from *p q*, and it will appear, consequently, less than the object, as at *i m*. The angle subtended to the eye by the reflection from the convex surface is, you perceive, much less than that of the reflection from the plane mirror; and the difference in apparent size of the

two reflections will bear the same proportion as the space between *p q* bears to the space between *n s*.

Robert. — I see: the ray that strikes against the glass at the point *p*, on the convex surface, would be reflected above the eye, because it would be nearly in the line of the perpendicular of the convex surface at that part.

Mr. P. — You are right: no ray from the point of the arrow, but that reflected from *n*, would be seen by the eye at *e*, for all the other rays would be reflected above or below it.

CONVERSATION XXV.

THE KITE.

Mr. P. — As the morning is remarkably mild and fine, we will take a walk; and, Frederick and Robert, bring your kites, that as you fly them I may endeavour to explain the cause of their ascent. (Frederick *and* Robert *fetch their kites, and accompany Mr.* Powell *and* Harriet *in their walk.*)

Frederick. — I should like very much to know what causes the kite, which is so much heavier than the air, to support itself at so great a height; it is a thing that has often puzzled me.

Robert. — It must be owing to the wind, for we know that kites will not fly when there is no wind.

Frederick. — Yes, Robert, I know that; but how is it that the wind can keep the kite in the air for a length of time, when all other things blown up by the wind soon come down again?

Robert. — Why, it is owing to the tail and the string.

Mr. P. — The tail and the string are, indeed, necessary to enable the kite to ascend; but you should be able to tell in what manner they produce this effect, otherwise your explanation conveys little information. The cause of kites flying is a question that has been thought worthy the investigation of the greatest mathematicians; but I shall try to make you understand it sufficiently, without reference to what would be, to you, puzzling demonstrations.

Frederick. — Shall I get my kite ready now?

Mr. P. — The field we are in will do very well; and this breeze is favourable to us. Let me look at your kite, Frederick, and see that it is properly balanced.

Frederick. — Is that of much importance?

Mr. P. — The kite will not fly steadily unless the sides are equally balanced; and it is for this reason the wings are added, which are of no use, provided the kite balances without them. (*Mr.* Powell *holds the kite up by the string, to try whether it balances, and whether the lower end dips down sufficiently.*) It is all right, I perceive, therefore get your string ready; and, Harriet, hold the kite up against the wind to assist its ascent. (Frederick *runs with the string, which draws the kite out of* Harriet's *hand, and it rises in the air.*) Stop, Frederick, you need not run any farther, but let out the string gently, as the kite draws it through your fingers.

Harriet. — What was the use of his running at all?

Mr. P. — The resistance of the air, as Frederick ran with the kite, acted in the same manner as the wind blowing against it, and therefore assisted the kite to rise in the air. The running is necessary also, in the first instance, to keep the kite in an oblique position until the tail has cleared the ground.

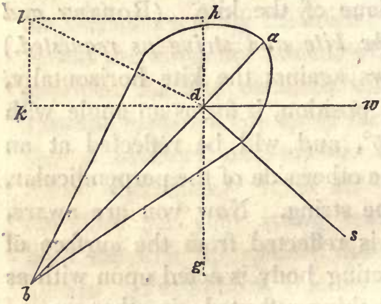
Frederick. — Is it absolutely necessary that the kite should be kept in a slanting direction to make it rise?

Mr. P. — The principle of kite-flying depends entirely upon it, as you will perceive on a slight explanation. Robert, hold up your kite obliquely, at an angle of about 45°, whilst Harriet holds the string in a direction perpendicular to the plane of the kite. (Robert *and* Harriet *hold the kite and string as requested.*) As the wind blows against the kite horizontally, whilst it is in this position, it forms an angle with its surface of 45°, and will be reflected at an equal angle on the other side of the perpendicular, represented by the string. Now you are aware, when any thing is reflected from the surface of another, the reflecting body is acted upon with as much force as the thing reflected; in other words, the action and re-action are equal, and in opposite directions. This is one of the laws of motion. The kite will, therefore, be acted upon by the reflection of the wind in the opposite direction to

that in which the wind is reflected; and, as Robert's kite is now held inclining at an angle of 45°, and the wind strikes it horizontally, the reflection will be perpendicular to the horizon, and the re-action on the kite, that is, the force of the reflected wind, will be directed perpendicularly upwards.

Harriet. — I do not exactly understand what you mean, papa: could you make the explanation clearer by showing us the direction and reflection of the wind in a drawing?

Mr. P. — I will endeavour to do so, my dear; and if I succeed in making you comprehend the theory of kite-flying, you will know more on the subject than the most successful kite-flyers generally do. Let *a b* represent Frederick's kite in the air, inclined at an angle of 45° to the surface



of the earth, and let *d s* represent the string, which we will suppose to be perpendicular to the plane of the kite *a b*. If the wind be blowing in the direction *w d*, when it strikes the kite at *d* (forming the angle *w d s* with the perpendicular), it will be reflected at an equal angle on the other side the perpendicular *d s*, that is, in the direction *d g*; and the force of the reflected wind, re-acting on

the kite in the opposite direction, will tend to carry it perpendicularly towards *h*. But the wind, in the direction *w d*, also acts on the kite at the same time, tending to carry it horizontally towards *k*, and the weight of the kite itself is tending to bring it down to the ground in the perpendicular direction *d g*. The kite is thus acted upon by three forces, — one impelling it towards *k*, the other towards *h*, and the third towards *g*.

HARRIET. — Then the poor kite is pulled three ways at once, — upwards, downwards, and sideways. It must be puzzled, I should think, to know which way to go.

MR. P. — It takes a direction between the three. If the weight of the kite pull it towards the ground with the force of two pounds, and if it be impelled horizontally with a force equal to two pounds and upwards also with the same force, the kite will move horizontally, and the two other forces will be destroyed.

FREDERICK. — How is that, father?

MR. P. — Because the forces in the opposite directions, *d g* and *d h*, act directly against each other, the one up and the other down, with equal strength, and therefore have no impelling power up or down, and leave the kite to be propelled solely by the horizontal power, which will act upon the kite with its whole force of two pounds. If the forces be unequal, that is, supposing the force

of the wind horizontally and upwards to be four pounds each, instead of two, whilst the weight of the kite remains the same, then it would be impelled horizontally towards *k* with a force of four, and upwards with the force of two pounds (which is the difference of power between the upward and downward forces). If we make the dotted line *d k* twice the length of *d h*, that being the proportion of their respective forces, and draw the parallelogram *d h l k*, then the diagonal *d l* will represent the direction of the kite under such circumstances. If the string of the kite be held tight, its horizontal motion is thereby prevented, and the whole force of the wind is directed upwards.

Frederick. — Then do the forces vary in power according to circumstances?

Mr. P. — Yes; the reflective force varies with the resistance offered to the wind by the reflecting body. For instance, if you were to slacken the string, the resistance of the kite to the wind would cease, and the kite would be carried along in the direction of the wind, till it fell to the ground; for as soon as the resistance ceased, the reflection would cease also. You can now try the experiment. Let the string run out rapidly, and by that means you will diminish the kite's resistance to the wind, and, consequently, lessen the reflecting power. (Frederick *lets the string run out, as his father directs, and the kite begins to descend.*)

HARRIET. — Look, Frederick, your kite is falling.

MR. P. — It has lost the reflective force of the wind, in consequence of the string being loosened, and can no longer support itself in the air. Pull the string in quickly, Frederick, or it will be down: — quick! quick!

FREDERICK. — (*Pulling in the string.*) Now it is rising again, and more perpendicularly than before.

MR. P. — Yes, you have pulled the string in so tightly, that the horizontal force of the wind cannot act upon the kite; and the reflective or perpendicular force is therefore brought into action with scarcely any counteracting power.

ROBERT. — What is the use of the kite's tail?

MR. P. — It has two very important uses: in the first place, its weight acts as ballast, and keeps the kite in an upright position by bringing the centre of gravity below the point of suspension.

ROBERT. — That might be done by fastening a small weight to the bottom.

MR. P. — It might so, but not nearly so well; for it would require a much heavier weight to answer the purpose, if fixed to the bottom of the kite, than it does when fastened at the extremity of a long string; and it is important to have the kite as light as possible. The tail also serves another most essential purpose, viz. to preserve the proper inclination of the kite.

Frederick. — In what manner does it do that, father?

Mr. P. — The "bobs," or pieces of paper fastened to the kite, present a considerable surface to the action of the wind; and if the weight at the end be not too heavy, it will be carried out by the wind, and will pull the kite into a slanting position, which, as I have shown you, is essential to its rising.

Robert. — I will try to fly my kite without the bobs, and see how it will do.

Mr. P. — Do so, Robert; there is nothing so convincing as experiments. (Robert *takes off the bobs from the tail, leaving the weight at the end.*) Harriet, my dear, hold it up, and let the kite with a naked tail have a fair trial. Now, Robert, run with it as fast as you can.

Harriet. — It scarcely rises high enough to clear the tail from the ground; and, now Robert stops, it is fallen.

Mr. P. — I concluded it would do so; for the tail hangs so perpendicularly without the bobs, that the kite cannot maintain its proper inclination. (Robert *comes back with his kite.*) Well, Robert, are you satisfied that the papers are of use?

Robert. — Yes; I must fasten them on again, for the kite flew nearly upright without them. What would be the effect of increasing the number and size of the bobs?

MR. P.—In that case the wind would carry the tail out too much, and the kite would be inclined too horizontally.

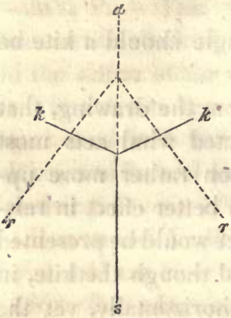
FREDERICK.—At what angle should a kite be inclined, to fly the best?

MR. P.—You perceive, from the drawing, that at an angle of 45° the reflected wind acts most perpendicularly; but a position rather more upright than that would have a better effect in raising the kite, as a larger surface would be presented to the action of the wind; and though the kite, in that case, would rise more horizontally, yet the advantage of having a larger surface exposed to the wind would more than compensate for any disadvantage in the loss of perpendicular force. The inclination of a kite may be greater in a strong wind than in a gentle breeze.

FREDERICK.—There is one thing, father, that takes place when a kite is flying, that must make an alteration in the reflection of the wind. You spoke of the kite as having a flat surface, but we know that, when it is in the air, the wind blows the two sides very much backwards: what effect has that on the reflection of the wind?

MR. P.—I am glad you have reminded me of the circumstance, though it does not alter our theory of kite-flying, as depending on the re-action of the reflected wind. The inclination of the sides of the kite produces an alteration in the direction of the reflected force of the wind, so as to bring it to bear more at right angles upon the surface of

the kite, as you may perceive from this drawing. The lines *k k* represent the sides of the kite bent backwards by the wind, and the dotted lines *r r* the directions in which the re-action of the reflected wind takes effect upon the inclining sides. The forces in this case are not directed perpendicularly upwards, but the re-action in this position operates much more effectually, as it is exerted at right angles to the kite, instead of acting obliquely against it, as before. Besides, as the reflected forces act on each side, at an equal angle from the perpendicular, the result of the composition of the two forces will be a perpendicular impulse in the direction *s d*.



ROBERT. — Would kites fly better if they could be made quite stiff and unyielding?

MR. P. — No, my dear, not so well by any means; for the action of the wind in different directions on the inclined sides of the kite tends to keep it steady, and prevents the kite from turning edgeways to the wind, which it would be apt to do if the surface were quite flat. A very simple experiment will show the advantage of inclining sides in steadying the kite. I will fasten a piece of string to the middle of this card, which is quite flat, and Harriet shall run with it as if she were flying a kite. (*Mr.* POWELL *fixes the string*

to the card, in the same way as the belly-band of a kite, and then gives it to HARRIET, *who runs with the card, which moves through the air very unsteadily.*)

ROBERT. — Harriet's kite wriggles about in all directions.

MR. P. — That is owing to the wind acting against it in different directions every instant, in consequence of the card not being kept sufficiently steady by the string to preserve it in the same inclination as Harriet runs with it. Stop, Harriet; bring your kite to me, and I will make it fly more steadily.

HARRIET. — (*Coming back with the card.*) I wish you would, papa; for it is all in a whirligig at present.

MR. P. — I will bend the card in the middle, lengthways, so as to resemble a kite when bent by the wind; and you will find that now the action of the air against the two surfaces as you run will steady the card. There, run, Harriet.

HARRIET. — (*Running with the card, which now moves steadily.*) Look, Frederick, at my kite now; it is flying almost as well as yours.

FREDERICK. — It falls, though, when you stop, whilst mine has kept up all this time without my moving.

MR. P. — Yes, Harriet's kite is too heavy for the size of it to remain in the air without the action of a very brisk wind. The running, and the force of the wind together, kept it up, though

when she stops it falls. But come, Frederick, pull in the string of your kite, and we will return home. I have explained to you, I hope satisfactorily, the principle on which the ascension of kites depends. There are, indeed, many phenomena connected with this subject that merit further attention; but they all depend upon, and may be explained by, the reflection of the wind from the inclined surface of the kite, occasioned by the resistance of the string. When your kite suddenly rises higher without your pulling the string, it is owing to an increased velocity of the wind increasing the reflecting force on the kite; when the kite is falling, the wind must have abated, or changed its direction. You may, upon the same principle, account for all the changes you may observe in the motion of the kite.

FREDERICK. — The kite seems to be quite a philosophical instrument.

MR. P. — It is, indeed; and you may, when amusing yourself with it, be very philosophically employed in finding out the causes of its evolutions in the air.

CONVERSATION XXVI.

SAILING.

Mr. P. — When we were at the sea-side, last summer, you must have noticed the ships and boats sailing in opposite directions at the same time, though the wind was blowing upon them all from the same point. Do any of you know by what means ships are made to sail against the wind?

Robert. — It is the rudder, by which the sailors turn the ships in the way they want them to go.

Mr. P. — The rudder will do much: but it will not do all, Robert; and no ship could keep at all to the windward by means of the rudder alone. But can you tell us, Robert, how the rudder acts in altering the direction of a ship?

Robert. — All I know is, that when the rudder is turned one way, the ship is turned the contrary way; and I suppose it is owing to the resistance of the water.

Mr. P. — So far, so good; but we must proceed a little further to be able to understand the cause of this effect.

HARRIET. — Yes, but, papa, you said the rudder alone would not make a ship sail against the wind: what is it, then, that does?

MR. P. — It depends upon the position in which the sails are placed to receive the wind, aided by the action of the rudder; but as the effect of the latter is most obvious, I will first explain its cause before I speak of the sails. Frederick, your little model of a steam boat will be of great use to us in illustrating the subject, therefore fetch it, and we will all go to the pond and give it a trial. (FREDERICK *brings the boat, and Mr.* POWELL *and his children repair to the pond.*)

HARRIET. — I shall be glad to see Frederick's little boat set to work; it looks so very pretty making its way through the water by itself.

MR. P. — It has, indeed, a very pleasing effect. The paddles are turned by a spring, similar to that of a watch. You perceive, now that I have wound it up, they turn round briskly. I will place the boat on the water, with the rudder at liberty, in the first instance, and it will cross over in a straight line towards the tree opposite, in which direction I will point the head. (*Mr.* POWELL *launches the boat on the water, and the working of the paddles carries it directly across the pond.*)

HARRIET. — There it goes, pretty thing! straight across.

MR. P. — Bring it to me, Frederick, and I will next tie the rudder on one side, and we shall see its effect in changing the direction of the boat.

(FREDERICK *fetches the boat, and gives it to his father, who ties the rudder, and then places it on the water in the same direction as before, with the paddles working.*) You observe that the boat, instead of going towards the tree opposite, is turning its head round to the same side as that on which the rudder is inclined, and it is coming back to this side of the pond.

ROBERT. — I said that the rudder would turn the ship round.

MR. P. — You did so, Robert; and now that we have seen the effect, let us find out the cause. You, Robert, have given us your explanation, and attribute it to the resistance of the water. Are you, Frederick, prepared to tell us how the resistance of the water operates on the rudder, so as to turn the boat?

FREDERICK. — Yes, father, I think I see how it is. As that side of the boat, towards which the rudder is turned, must meet with more resistance from the water than the other side, it cannot, in consequence, move so fast; therefore, the other side, which meets with no such obstruction, by moving quicker, must turn the boat round, in the same way that a carriage turns round when one horse trots faster than the other.

MR. P. — Very well explained, indeed, Frederick. I did intend to mention to you in what manner the water acts upon the rudder to cause its resistance; but your explanation will, perhaps, be sufficient for our present purpose, and we will

next proceed to hoist our sails. I will let the rudder continue tied, as in the last experiment; though I shall not now use the paddles, but trust only to the wind, which is blowing from east to west, along the pond. I will place the sails in an oblique position to the wind, and again launch the boat towards the tree, which is nearly north, therefore the wind blows across the vessel. (*As the wind strikes against the sails, the boat begins to sail across the pond, and arrives on the opposite bank, a little to the westward of the tree.*)

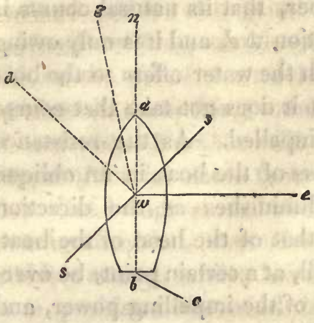
Robert. — When put on the pond before, with the rudder tied in the same way and the paddles working, the boat went quite round towards the east; but look! the wind has taken it right across, and rather to the west of the tree.

Mr. P. — Well, Robert, you must now be convinced that it is not the rudder alone that alters the course of a ship, for you have seen the boat carried in opposite directions with the rudder fixed in the same place each time.

Robert. — Yes, I see that the sails can alter the direction too. Can you explain to us, father, how this effect is produced by inclining the sails to the wind?

Mr. P. — I will endeavour to do so, Robert, in such a way that, by paying a little attention, you may be able to understand the cause of ships sailing against the wind. This drawing will assist in making the subject more clear: *a b* represents the boat, *b c* the rudder, *s s* the sail, and *e w* the direc-

tion of the wind from east to west. The wind, in



this position of the sail, strikes upon it in an oblique direction, and is reflected from it at an equally oblique angle, in the direction *w b*. The reflected wind, therefore, re-acts upon the sail, in the direction from *b* to *w*, with nearly equal force to that of the wind blowing from *e* to *w*. The vessel being thus acted upon at the same time by two nearly equal forces, (the one in the direction from *e* to *w*, and the other in the direction from *b* to *w*,) is inclined to take a course between the two, towards *d*, and it would be propelled in that direction were the head of the boat pointed towards it. The water, however, resists the motion of the boat in that course, so long as the head is kept pointed towards *n*, and it is obliged to proceed in the direction which offers least resistance to its progress through the water; that is, with its head foremost. As the moving power is, however, exerted in the direction from *w* to *d*, the vessel will make some way in that direction, and the real course of the vessel will be *w g*.

Robert. — But the boat must move sideways, then, if it go from *w* to *g*, whilst the head remains pointed towards *n*.

Mr. P.—It does, indeed, move rather obliquely; but you must remember, that its natural course is the very oblique direction *w d*, and it is only owing to the resistance which the water offers to the boat moving sideways, that it does not take that course towards which it is impelled. As the resistance offered to the progress of the boat in an oblique direction gradually diminishes as the direction approaches nearer to that of the head of the boat, the extra resistance will, at a certain point, be overcome by the direction of the impelling power, and the vessel will sail in that course.

Frederick.—Then I suppose that the greater the resistance of a boat in moving sideways, or obliquely, the nearer it will be able to sail against the wind?

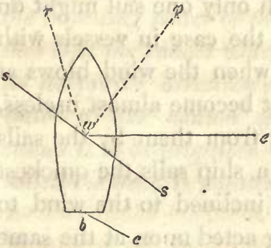
Mr. P.—You are right. The keel at the bottom of ships tends greatly to produce this effect, as it presents a direct resistance to the motion of the vessel sideways.

Robert.—How is it that the head of the ship does not turn from the wind, and so let the ship go in the course that offers least resistance?

Mr. P.—The rudder prevents it. The principal use of the rudder in sailing is to keep the head of the ship in its right course, that the sails may be properly adjusted to catch and reflect the wind, so as to propel the vessel forward. Were it not for the rudder, ships would be blown in the direction of the wind, and be incapable of guidance.

Robert. — Then it is the rudder, after all, that makes ships sail against the wind.

Mr. P. — Ships could not sail against the wind without the aid of the rudder, but the rudder of itself would do nothing towards keeping the ship in its course, unless the sails were properly placed. Suppose, for instance, that the sails of the ship, instead of being set as before, were placed in the contrary direction, across the vessel, as represented in this drawing, whilst the rudder remained in the same position; the wind blowing from *e* to *w* would be reflected towards *r*, and would re-act upon the sail in the direction from *r* to *w*. The sail being thus acted upon by two forces, one from *e* to *w* and the other from *r* to *w*, the propelling power would be in a direction between both, that is from *p* to *w*, and the vessel would move backwards, with the stern foremost, till it turned round so as to bring the sail *s s* in a line with the direction of the wind, when it could no longer take any effect upon the sail.



Harriet. — You say, papa, that ships can sail against the wind; but I suppose they cannot sail directly against it?

Mr. P. — No, my dear, not directly; for if the head of the ship were pointed directly against the wind the ship would be blown backwards. By

sailing against the wind, I mean, sailing in a direction different from that in which the wind blows; as, for instance, sailing north when the wind is blowing from the east or west. When ships sail still nearer to the wind, they can make but little progress, as the wind must then strike the sails so obliquely as to have little effect upon them.

Robert. — Of course a ship sails the fastest when the wind is blowing at its stern, for then the sails catch it all.

Mr. P. — A vessel with only one sail might do so, but it is by no means the case in vessels with two or three masts; for when the wind blows at the stern, the sails in front become almost useless, because the wind is taken from them by the sails nearest the stern. Such a ship sails the quickest when it is just sufficiently inclined to the wind to admit of all the sails being acted upon at the same time.

Frederick. — What do sailors mean by *tacking?*

Mr. P. — When the wind blows too closely in the direction of a ship's course to allow of its sailing towards that point, it is made to sail as near to the course as possible, and is then turned back to start from a fresh point. In this manner the ship would at length arrive, in a zig-zag direction, at the point of its destination.

Harriet. — It must be very tiresome, to go backwards and forwards in that manner.

Robert. — Yes; when you have just got in sight of land, to be turned back, and taken out to sea again, must be very provoking.

Mr. P. — Well, my children, I think I have now told you sufficient respecting the general principles of sailing, to enable you to understand why ships should sail different ways with the same wind. With Frederick's little steam-boat you will be able to carry the principles of sailing into practice on a small scale; and you will always find that *it is the position of the sails which causes the impelling power of the wind to vary its direction; that it is the rudder which keeps the head of the ship in its proper direction; and the resistance of the water to the motion of the vessel sideways, that causes it to be propelled nearly in the course towards which the head is pointed.*

CONVERSATION XXVII.

FLYING.

Harriet. — What a delightful thing it must be to be able to fly, like the birds. Is it known, papa, how they are able to support themselves in the air?

Mr. P. — Yes, my dear: flying depends entirely upon the rapid action of the wings of birds upon the air. The muscles which move the wings of birds are exceedingly powerful; and when the wings strike against the air with great force, the resistance they meet with is sufficient to raise the bird from the ground.

Frederick. — What force would be sufficient to raise them?

Mr. P. — A power rather greater than the weight of their bodies. You may conceive that if a bird be able to lift its body by the strength of its wings, when resting them upon a firm support, a sufficient *purchase*, or hold, upon the air would only be requisite to enable the wings to raise it

from the ground. This purchase birds obtain by the rapid motion of their wings.

Robert. — But all birds do not move their wings equally quick; and the larger birds seem to move their wings more slowly than the little ones.

Mr. P. — Yes, they do; but the wings of large birds are proportionably larger, and therefore take much more hold upon the air, and move through a greater space at each stroke.

Harriet. — But some birds seem to fly without moving their wings at all. I cannot understand that.

Mr. P. — It is only the birds with large wings that can do so; and their apparently horizontal motion through the air depends upon the same principle as that of the sailing of ships against the wind. When the bird expands its wings and is motionless, its weight tends to bring it down perpendicularly to the earth; but the expanded wings and tail presenting great resistance to the air in that direction, the bird moves in the course which offers least resistance, viz. in that towards which its head is turned; and it comes gradually to the earth in a very oblique course. In the same manner I explained to you the cause of a ship sailing in the direction towards which the head is pointed. Birds often seem, indeed, to move quite horizontally whilst their wings are motionless; but this appearance is owing to our not being able to see, from below, the exact course

of their flight. Their progress through the air, in such cases, depends entirely upon their gravitating force; that is, upon the power with which they are drawn towards the earth.

ROBERT. — But I have seen birds, after darting downwards for some time, rise in the air again without moving their wings.

MR. P. — You are determined, Robert, to puzzle me, if you can; but, perhaps, I shall puzzle you when I tell you, that the rising in the air you have noticed, depends upon the force with which the bird falls downwards.

HARRIET. — Well, papa, that is a puzzle indeed! What do you think now, Robert? Will you give it up?

ROBERT. — Yes; I think any body will find it a hard matter to make that out.

MR. P. — I think a very satisfactory clue to the puzzle will be discovered, when I mention the Russian slides.

FREDERICK. — Yes, I remember; the force that sent the carriages down one hill carried them up another. Then, is it in the same way that the force which the bird gains in falling down sends it up again?

MR. P. — You have guessed right, Frederick.

ROBERT. — In the Russian slides there was a hill made on purpose for the carriage to slide up; but the bird has nothing to support itself upon.

MR. P. — You forget the air, Robert.

HARRIET. — But still, papa, I am puzzled to think what can make the bird alter its course, and suddenly rise, if it does not move its wings.

MR. P. — The principal cause of the change in the direction of its flight is produced by the tail, which acts as the rudder of a ship in varying the course of the bird up and down. Some scientific men, I am aware, consider it to be a vulgar error to suppose that the tail of a bird acts as a rudder in changing its course; but the vulgar opinion is nevertheless correct. It is true, the tail can have little influence in directing the horizontal motion; but, in ascending and descending, it is of the greatest utility.

FREDERICK. — In what way does a bird move its tail to make it rise?

MR. P. — We will suppose a bird to be descending rapidly, at an angle of 25° to the horizon, and to have acquired the force it would have done in descending from a Russian slide of the same inclination. When it arrives at the bottom of the intended descent (during which the tail has been nearly in a line with the body), the bird points its head upwards, spreads out its tail, and raises it. The elevated tail presents considerable resistance to the air, and the body of the bird is thereby pointed upwards, in the same manner as a ship is turned by the rudder. The direction in which the bird's body is then pointed being that which offers least resistance to its progress, it continues in an upward course so long as the im-

pelling power (gained in the previous descent) overcomes the gravitating force, which tends to draw the bird to the earth.

FREDERICK. — Then, I suppose, when a bird wants to descend, it inclines its tail downwards.

MR. P. — Yes; that motion of the tail would bring its head in a direction more perpendicular to the earth, and it would therefore descend the faster.

ROBERT. — If the tail directs birds only in ascending and descending, what is it that gives them their direction sideways?

MR. P. — Their wings produce the alteration in their horizontal course. On turning to the left, a bird has only to move its head in that direction, at the same time striking more forcibly with its right wing, and the object will be accomplished: on turning to the right, the motions of the head and wing must be reversed.

FREDERICK. — Just in the same way, I suppose, that we turn a boat, by pulling with one oar harder than with another.

MR. P. — Exactly the same.

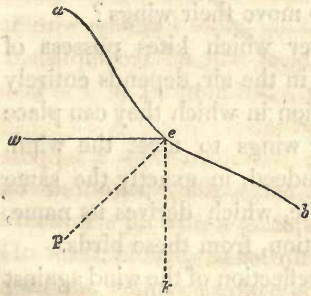
ROBERT. — If the air offer so much resistance to the descent of birds, when their wings are spread out, I should suppose that when they are once risen in the air, they can keep themselves there with very little labour.

MR. P. — Yes, my dear; when they are risen as high as they wish, very little exertion is required to sustain their bodies at that height.

When flying rapidly in a horizontal course, the lateral resistance of the air, and its reflection from their bodies, must be more than sufficient to support them. The whole of their strength may then be exerted horizontally.

FREDERICK. — Does the resistance of the air, as birds move through it horizontally, help to keep them up?

MR. P. — Yes. The effect produced by their motion through the air is similar to that of the wind blowing against them. I have shown you that, in the case of ships and kites, when the wind strikes against the inclined sails, or paper, it is reflected at an equal angle, and re-acts against the sails or kite in an opposite direction. Supposing



this curved line, *a b*, therefore, to represent the breast of a bird flying horizontally through the air, *w e* would be the direction of the air's resistance, against which the point *e* is impelled. As *p e* is perpendicular to the curve at the point *e*, the air would be reflected at an equal angle on the opposite side of it, that is, in the direction *e k;* and the point *e* would be acted upon by two forces, — one in the direction from *w* to *e*, and the other from *k* to *e*. The real direction, from the composition of the two forces, therefore, would be the

mean between the two, or from *p* to *e*. The same would be the case in all other parts of the curvature of the breast of the bird. Thus, you perceive, if the bird moved in the direction from *e* to *w*, it would receive an impulse upwards from the resisting force in front, as well as be supported by the resistance of the air beneath. If the motion were very rapid, birds would actually be raised in the air by the exertion of their strength in moving horizontally; as the impulse of the reflected air upwards would then be so great as to overcome the force of gravity, by which they are drawn towards the earth.

Frederick. — Is it owing to this cause that the birds called kites keep themselves stationary in the air, without seeming to move their wings?

Mr. P. — The power which kites possess of *soaring*, as it is termed, in the air, depends entirely upon the slanting position in which they can place their bodies and their wings to meet the wind. They are supported, indeed, in exactly the same manner as the paper kite, which derives its name, at least, if not its invention, from these birds.

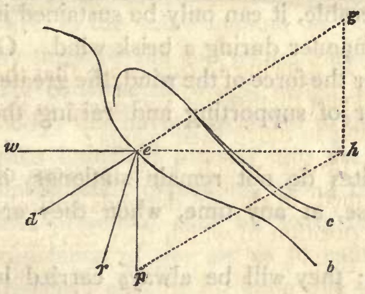
Robert. — But the reflection of the wind against the paper kite, father, you said was occasioned by the resistance of the string; and as the bird is not tied to any thing, how can it offer sufficient resistance to produce the reflection of the wind?

Mr. P. — That is a very proper question, Robert; and I will endeavour to make you understand how the reflection is produced without the

string, or the motion of the bird. In this case, as in that of the bird ascending by the velocity gained in its descent, the weight of the kite, or the force with which it is drawn to the ground, supports it in the air.

HARRIET. — How very odd! What, papa, is the same thing that is pulling the bird towards the ground, the cause of its being kept in the air?

MR. P. — Indeed it is so, strange as it may sound. I will show you how this effect is produced. Suppose *a b c* to represent the breast, tail, and wing of a kite soaring in the air in an oblique position. If the bird be a large one, it will weigh four pounds, and will, therefore, be



drawn towards the earth, in the perpendicular direction *e p*, with a force equal to four pounds. The wind, blowing in the direction *w e*, and striking upon the oblique surface of the bird, is reflected towards *e r*; the reaction is, consequently, from *r* to *e*, and the real direction resulting from the composition of the two forces is from *d* to *e*. Now, supposing the actual force of the wind acting upon the whole inclining surface of the bird from *d* to *e*, (and tending to carry it towards *g*), to be eight pounds; the bird would then be acted upon by

the gravitating force *e p*, with half the power (viz. four pounds) by which it would be impelled towards *g*, and the actual motion of the bird would be in the direction *e h*, which is the diagonal of the parellelogram *e g h p*, the two sides of which, *e g* and *e p*, represent the directions and comparative power of the two contending forces.

FREDERICK. — Then the weight of the bird acts in the same manner as the string of the paper kite, in producing a reflecting power?

MR. P. — It does so; but as the weight of the bird is so considerable, it can only be sustained in the air in this manner during a brisk wind. Of course, the greater the force of the wind, the greater will be its power of supporting and raising the kite.

ROBERT. — Kites do not remain stationary in the air, I suppose, at any time, when they are soaring?

MR. P. — No; they will be always carried in the direction of the wind, though their weight, which acts as a string pulling them towards the ground, prevents them from being blown away rapidly, like the clouds.

HARRIET. — I wish, papa, some one would take an idea from the birds, to construct a machine that would make us fly too.

MR. P. — The attempt has been often made, but without success. The weight of the human body is so great, that we have scarcely strength enough in our arms to raise ourselves, even when

taking hold of unyielding substances; and all attempts to get a purchase, or hold, upon the air, strong enough to raise the body from the ground, have hitherto failed. The most successful attempt at flying that I have heard of was that of an ingenious baronet in Yorkshire, who contrived wings by which he could fly from tree to tree.

HARRIET. — How did he do that, papa? I should like above all things to see him flying.

MR. P.— He proceeded upon the principle of obtaining a horizontal motion by downward pressure, in the same manner as birds do when they fly through the air without moving their wings. He constructed wings, which he attached to his body; and having ascended to the top of a tree, he then launched himself into the air. The wings immediately expanded, as he began to descend, and presented such an extended surface to the resistance of the air as to cause a very gradual descent; and, by inclining one of the wings to the ground, the flying baronet was enabled to give to his fall an oblique direction, so as to arrive at the bottom of another tree at some distance. Thus he may literally be said to have flown from tree to tree.

FREDERICK. — Do you consider it impossible, father, for any machine to be invented to enable us to fly?

MR. P. — Not absolutely impossible; for if an apparatus could be contrived in which the muscles of the legs, as well as of the arms, could be made to

act with advantage against the air, and at the same time the descent were retarded by the expansion of an extensive surface, I can suppose it very possible for a man to support himself, and move through the air, provided he commenced his aërial excursion from a considerable height. The most probable means, however, by which man can hope to traverse the air at will, is by the aid of steam engines.

Harriet. — Steam engines, papa! What, fly with those heavy things?

Mr. P. — It is possible for steam engines to be made not heavier than a man, yet possessing more than ten times the power of one. If a proper apparatus could be invented to be worked against the air by such an engine, the attempt to fly, hitherto so unsuccessfully made, might indeed be carried into effect.

Harriet. — I wish it could. I do so envy the birds on that account.

Robert. — What prevents people from using balloons to sail with through the air?

Mr. P. — Because no effectual plan has been discovered of guiding them. They move always in the direction of the wind; and though, I believe, aëronauts have succeeded, by the use of large wings, in altering their course in some small degree, yet no material deviation from the course of the wind can be expected to be accomplished.

Robert. — Why cannot they use sails and a rudder, as on board a ship?

Mr. P. — You must remember, Robert, that the principal cause of a ship deviating from the wind is the resistance which the water offers to its motion sideways, and that the rudder acts only when it meets a resisting force. Balloons, on the contrary, meet with no resisting force against which a rudder could act with any effect, since they move nearly as fast as the wind. The only resisting power that could be turned to account in guiding balloons is the resistance of the air to their ascent; and that would have scarcely any effect against the wind.

Harriet. — If you could invent a sailing balloon or a flying machine, papa, I might go to school to-morrow flying smoothly through the air, instead of jolting along the road in a carriage till I am almost tired to death; and how it would astonish them all at school!

Robert. — You will astonish them enough, Harriet, if you only tell them some of the things we have learnt since we came home. — I wonder what my schoolfellows will say when I tell them they cannot see my black hat.

Harriet. — And mine, when I tell them that fanning makes the air hotter.

Robert. — I shall have plenty of things to puzzle them with. — I shall tell them that cold iron is as hot as wool — that the wind is not cold — that snow is very hot — that coals do not burn — that burning is not destroying — that fire is hidden in cold water — that darkness is light — that water

may boil by being cooled — that white is not white, and that black cannot be seen — that nothing is of a natural size — that a mite seen as large as a crab is not magnified — that birds rise in the air by being pulled down to the earth — that ——

Harriet. — Do not forget to tell them, Robert, that you cannot distinguish hot from cold — ha, ha, ha!

Robert. — You will never have done with that, Harriet.

Harriet. — Yes, I will — till we meet again at midsummer.

Mr. P. — I hope you will all, in the mean time, often think upon the subjects of our conversations. The knowledge you have gained will, I trust, be of use in enabling you to explain many other phenomena than those I have more particularly mentioned; and should any natural occurrences present themselves that you cannot understand, I wish you would note them down, and when we again meet, I may, perhaps, be able to throw some light upon the matter.

Frederick. — Thank you, father, for the very interesting information you have already given us. It has made me wish to know a great deal more on these subjects, and I shall be quite delighted to continue our conversations at midsummer.

THE END.

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